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(12) **United States Patent**  
**Tang et al.**

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(54) **SYNTHESIS OF DIINDOLYLMETHANES AND INDOLO[3,2-B]CARBAZOLES, COMPOUNDS FORMED THEREBY, AND PHARMACEUTICAL COMPOSITIONS CONTAINING THEM**

(71) Applicant: **Wisconsin Alumni Research Foundation**, Madison, WI (US)

(72) Inventors: **Weiping Tang**, Middleton, WI (US); **Xiaoxun Li**, Mountain View, CA (US); **Dongxu Shu**, Lake Bluff, IL (US); **Gabrielle N. Winston-McPherson**, Madison, WI (US)

(73) Assignee: **Wisconsin Alumni Research Foundation**, Madison, WI (US)

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days. days.

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**C07D 403/06** (2006.01)  
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CPC ..... **C07D 209/14** (2013.01); **C07D 403/06** (2013.01); **C07D 405/14** (2013.01)

(58) **Field of Classification Search**  
None  
See application file for complete search history.

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*Primary Examiner* — Shawquia Jackson

(74) *Attorney, Agent, or Firm* — Joseph T. Leone, Esq.; DeWitt Ross & Stevens S.C.

(57) **ABSTRACT**

Described is a method to make diindolylmethanes and indolyl/pyrrolylmethanes, The method includes the steps of contacting an ether comprising an arylpropargyl moiety and an amine-protected, substituted or unsubstituted aniline moiety with a substituted or unsubstituted indol or a substituted or unsubstituted pyrrole, in the presence of a metal-containing catalyst, for a time and at a temperature to cause an annulation/arylation cascade reaction that yields a diindolylmethane or a indolyl/pyrrolylmethane. The resulting compounds are effective to modulate activity of arylhydrocarbon receptors, to inhibit activity of PCSK9, and to stimulate secretion of glucagon-like peptide 1 in mammals.

**3 Claims, No Drawings**

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**SYNTHESIS OF DIINDOLYLMETHANES  
AND INDOLO[3,2-B]CARBAZOLES,  
COMPOUNDS FORMED THEREBY, AND  
PHARMACEUTICAL COMPOSITIONS  
CONTAINING THEM**

CROSS-REFERENCE TO RELATED  
APPLICATIONS

Priority is hereby claimed to provisional application Ser. No. 62/107,707, filed Jan. 26, 2015, and to provisional application Ser. No. 62/033,410, filed Aug. 5, 2014, both of which are incorporated herein by reference.

FEDERAL FUNDING STATEMENT

This invention was made with government support under GM088285 awarded by the National Institutes of Health. The government has certain rights in the invention.

FIELD OF THE INVENTION

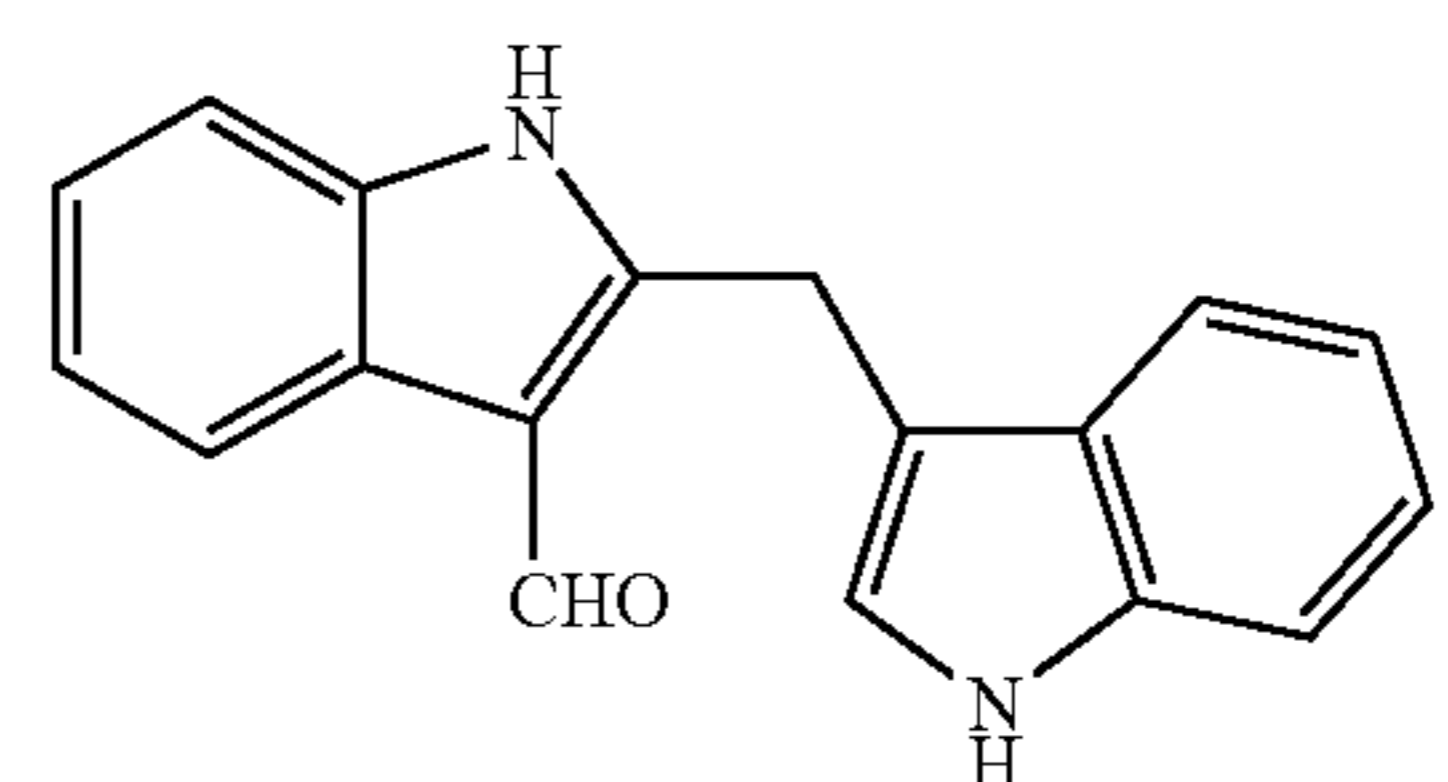
Disclosed herein are novel diindolyl compounds that are effective to modulate activity of arylhydrocarbon receptors, to inhibit activity of PCSK9, and to stimulate secretion of glucagon-like peptide 1 in mammals.

BACKGROUND

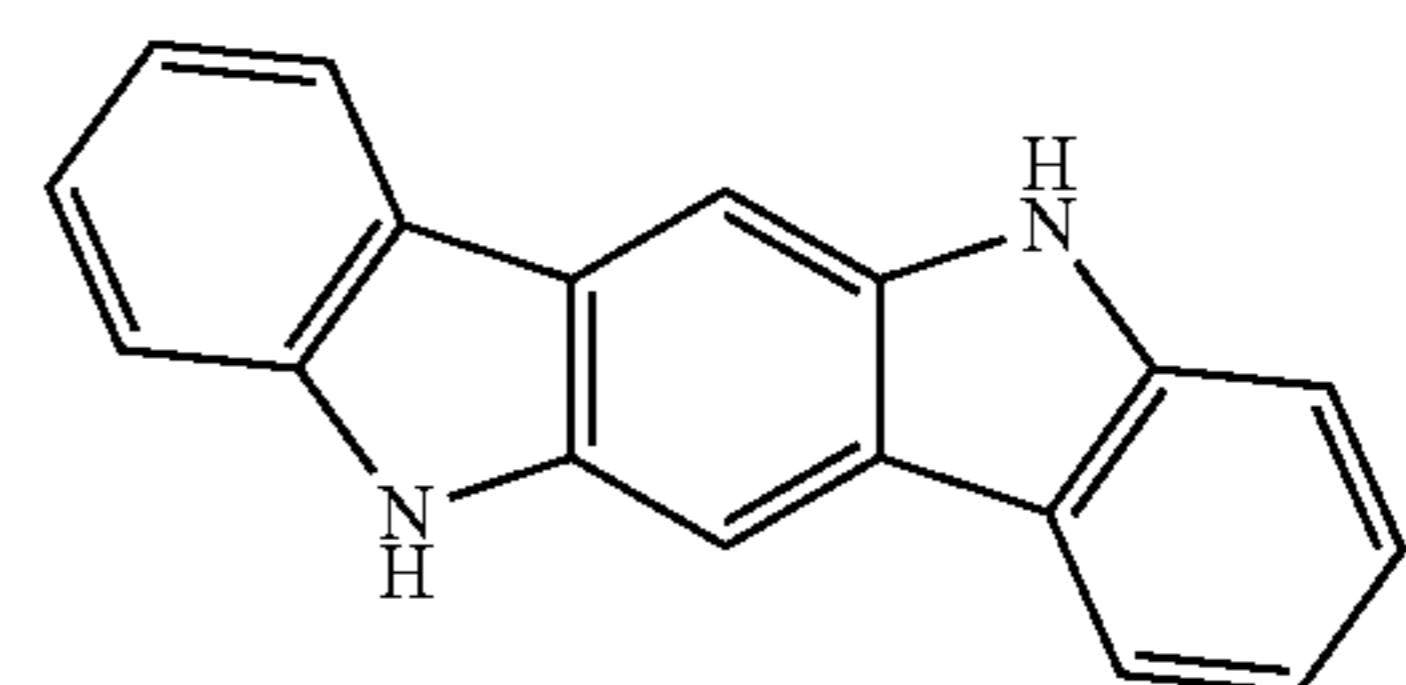
Indole is one of the most abundant heterocycles in bioactive natural products and pharmaceutical agents. Not surprisingly, numerous efforts have been devoted to the preparation of indoles from a diverse range of starting materials. For recent-reviews on indole synthesis, see: (a) Barluenga, J.; Rodriguez, F.; Fananas, F. J. *Chem. Asian J.* 2009, 4, 1036. (b) Taber, D. F.; Tirunahari, P. K. *Tetrahedron* 2011, 67, 7195. (c) Vicente, R. *Org. Biomol. Chem.* 2011, 9, 6469. (d) Platon, M.; Amardeil, R.; Djakovitch, L.; Hierso, J.-C. *Chem. Soc. Rev.* 2012, 41, 3929. For recent examples of indole annulations, see: (a) Cui, X.; Li, J.; Fu, Y.; Liu, L.; Guo, Q.-X. *Tetrahedron Lett.* 2008, 49, 3458. (b) Oda, Y.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* 2012, 14, 664. (c) Ackermann, L.; Lygin, A. V. *Org. Lett.* 2012, 14, 764. (d) Inamoto, K.; Asano, N.; Nakamura, Y.; Yonemoto, M.; Kondo, Y. *Org. Lett.* 2012, 14, 2622. (e) Xia, X.-F.; Wang, N.; Zhang, L.-L.; Song, X.-R.; Liu, X.-Y.; Liang, Y.-M. *J. Org. Chem.* 2012, 77, 9163. (f) Song, W.; Ackermann, L. *Chem. Commun.* 2013, 49, 6638. Most previous efforts, however, have focused on indole annulation alone. The efficiency of the synthesis can be increased significantly if the event of indole annulation is coupled with other transformations in a cascade manner. For example, a tandem indole annulation/(4+3) cycloaddition for the construction of both indole and a seven-membered ring simultaneously in the synthesis of cyclohepta[b]indoles is described in the literature. Shu, D.; Song, W.; Li, X.; Tang, W. *Angew. Chem. Int. Ed.*, 2013, 52, 3237. For a synthesis of cyclohepta[b]indoles by a different type of (4+3) cycloaddition, see: Han, X.; Li, H.; Hughes, R. P.; Wu, J. *Angew. Chem. Int. Ed.* 2012, 51, 10390. Diindolylmethanes are not only present in natural products such as malassezin but also important precursors for other naturally occurring heterocycles such as indolocarbazoles 2 and 3a-3f: Wille, G.; Mayser, P.; Thoma, W.; Monsees, T.; Baumgart, A.; Schmitz, H. J.; Schrenk, D.; Polborn, K.; Steglich, W. *Bioorg. Med. Chem.* 2001, 9, 955. Kramer, H. J.; Podobinska, M.; Bartsch, A.; Battmann, A.; Thoma, W.; Bernd, A.; Kummer, W.; Irlinger, B.; Steglich,

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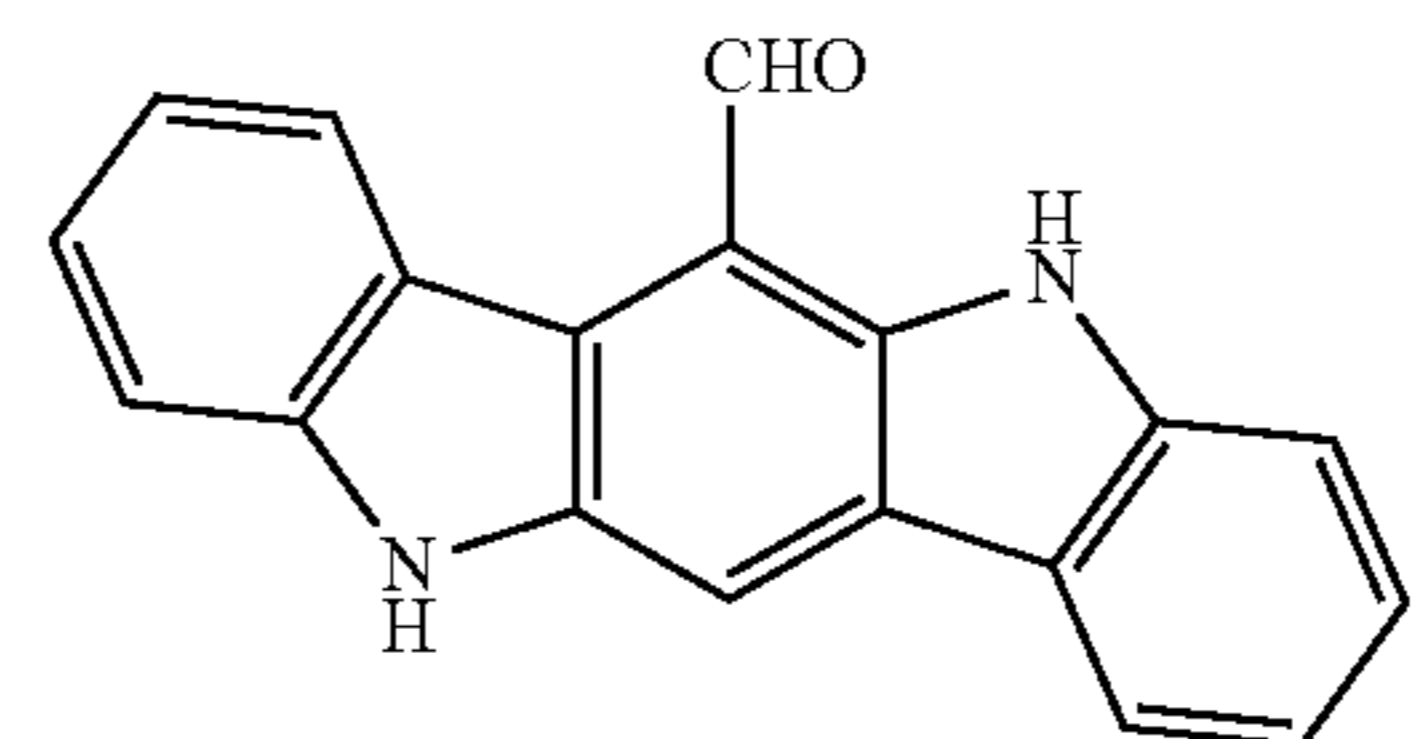
W.; Mayser, P. *ChemBiochem* 2005, 6, 860. Wahlstrom, N.; Romero, I.; Bergman, J. *Eur. J. Org. Chem.* 2004, 2593. Knolker, H. J.; Reddy, K. R. *Chem. Rev.* 2002, 102, 4303. Schmidt, A. W.; Reddy, K. R.; Knoelker, H.-J. *Chem. Rev.* 2012, 112, 3193.



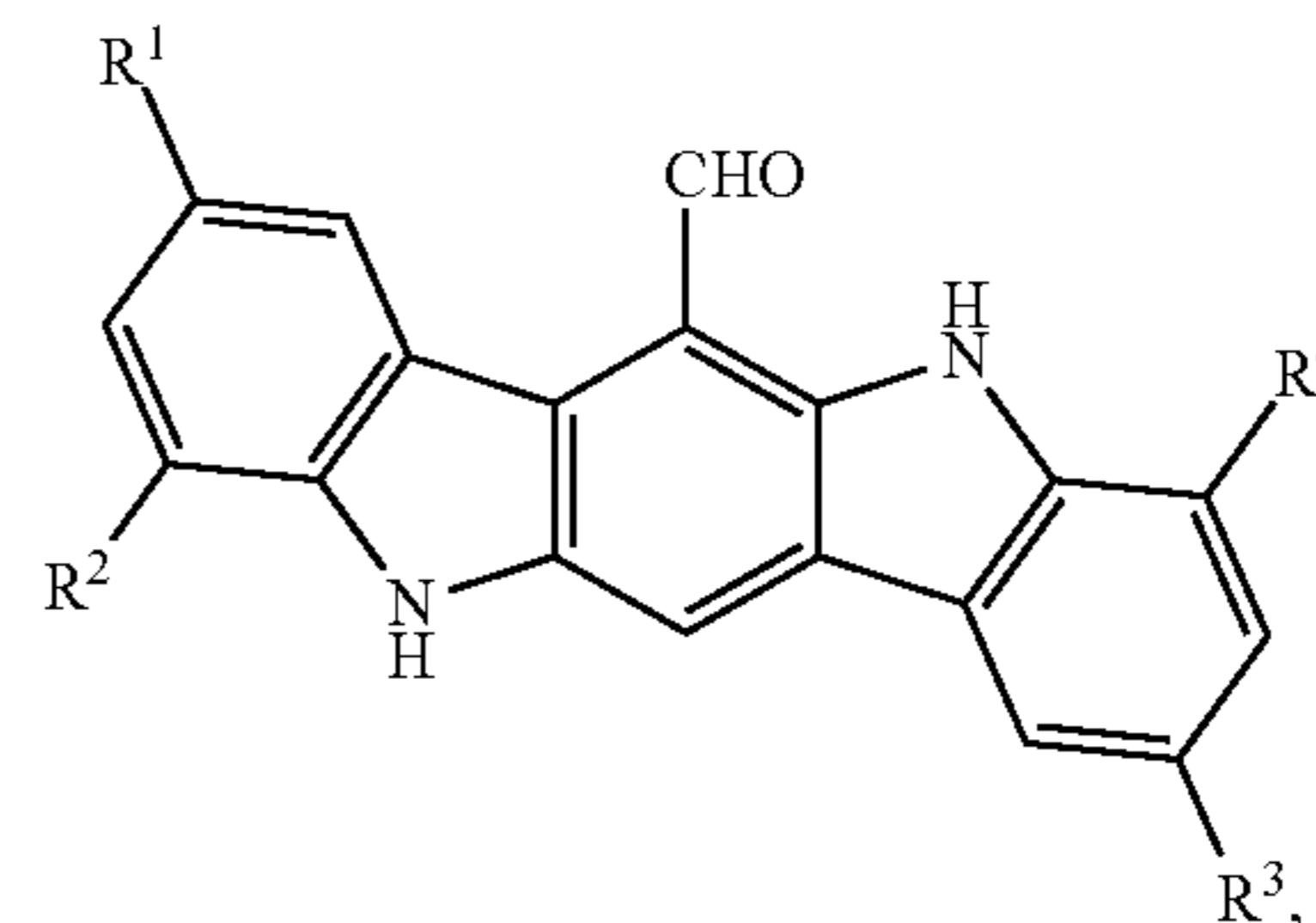
malassezin



Indolo[3,2-b]carbazole (ICZ)



6-formylindolo[3,2-b]carbazole (FICZ)

3b, R<sup>1</sup> = OH, R<sup>2</sup> = H, R<sup>3</sup> = OH, R<sup>4</sup> = H3c, R<sup>1</sup> = OH, R<sup>2</sup> = R<sup>3</sup> = H, R<sup>4</sup> = OH3d, R<sup>1</sup> = H, R<sup>2</sup> = R<sup>3</sup> = OH, R<sup>4</sup> = H3e, R<sup>1</sup> = R<sup>2</sup> = R<sup>3</sup> = H, R<sup>4</sup> = OH3f, R<sup>1</sup> = OH, R<sup>2</sup> = R<sup>3</sup> = R<sup>4</sup> = H

Malassezin, ICZ, and FICZ are potent agonists of aryl hydrocarbon receptor (AhR), which is best known for mediating the toxicity of dioxin and related environmental toxins. Denison, M. S.; Soshilov, A. A.; He, G.; Degroot, D. E.; Zhao, B. *Toxicol. Sci.* 2011, 124, 1. Recent studies showed that AhR also played a critical role in immune cell differentiation, promoting intestinal immune function, and the development of the prostate. See Quintana, F. J.; Basso, A. S.; Iglesias, A. H.; Korn, T.; Farez, M. F.; Bettelli, E.; Caccamo, M.; Oukka, M.; Weiner, H. L. *Nature* 2008, 453, 65. (b) Stevens, E. A.; Mezrich, J. D.; Bradfield, C. A. *Immunology* 2009, 127, 299; Li, Y.; Innocentin, S.; Withers, D. R.; Roberts, N. A.; Gallagher, A. R.; Grigorieva, E. F.; Wilhelm, C.; Veldhoen, M. *Cell* 2011, 147, 629; Kiss, E. A.;

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Vonarbourg, C.; Kopfmann, S.; Hobeika, E.; Finke, D.; Esser, C.; Diefenbach, A. *Science* 2011, 334, 1561; and Mehta, V.; Vezina, C. M. *Differentiation* 2011, 82, 211, respectively.

It has been demonstrated that selective AhR modulators inhibit prostate tumor metastasis and have anti-asthmatic effects in animal models. Indolo[3,2-b]carbazoles are also important class of organic electroluminescent compounds. See Fritz, W. A.; Lin, T.-M.; Safe, S.; Moore, R. W.; Peterson, R. E. *Biochem. Pharmacol.* 2009, 77, 1151; Jeong, K.-T.; Hwang, S.-J.; Oh, G.-S.; Park, J.-H. *Int. Immunopharmacol.* 2012, 13, 377; Gu, R.; Robeyns, K.; Van Meervelt, L.; Toppet, S.; Dehaen, W. *Org. Biomol. Chem.* 2008, 6, 2484; and Boudreault, P. L. T.; Wakim, S.; Tang, M. L.; Tao, Y.; Bao, Z. A.; Leclerc, M. J. *Mater. Chem.* 2009, 19, 2921.

Rearrangement of the symmetrical 3,3'-diindolylmethanes to 2,3-diindolylmethanes could be realized using iodine as the catalyst. Gu, R.; Hameurlaine, A.; Dehaen, W. *Synlett* 2006, 1535. Gu, R.; Hameurlaine, A.; Dehaen, W. *J. Org. Chem.* 2007, 72, 7207. Low yields, however, were observed when substituted indoles were employed as the substrates. Synthesis of non-symmetric 2,3-diindolylmethanes requires the joining of two different indoles in multiple steps. Tholander, J.; Bergman, J. *Tetrahedron Lett.* 1998, 39, 1619. Tholander, J.; Bergman, J. *Tetrahedron* 1999, 55, 6243. Wahlstrom, N.; Stensland, B.; Bergman, J. *Synthesis* 2004, 1187.

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## SUMMARY

Disclosed herein is a synthesis of symmetrical or unsymmetrical diindolylmethanes and 1-indolyl-1-pyrrolylmethanes via a platinum-catalyzed indole annulation/arylation cascade reaction. The diindolylmethanes and 1-indolyl-1-pyrrolylmethanes can be further reacted to yield the corresponding indolyl (or indolyl/pyrrolyl) carbazole.

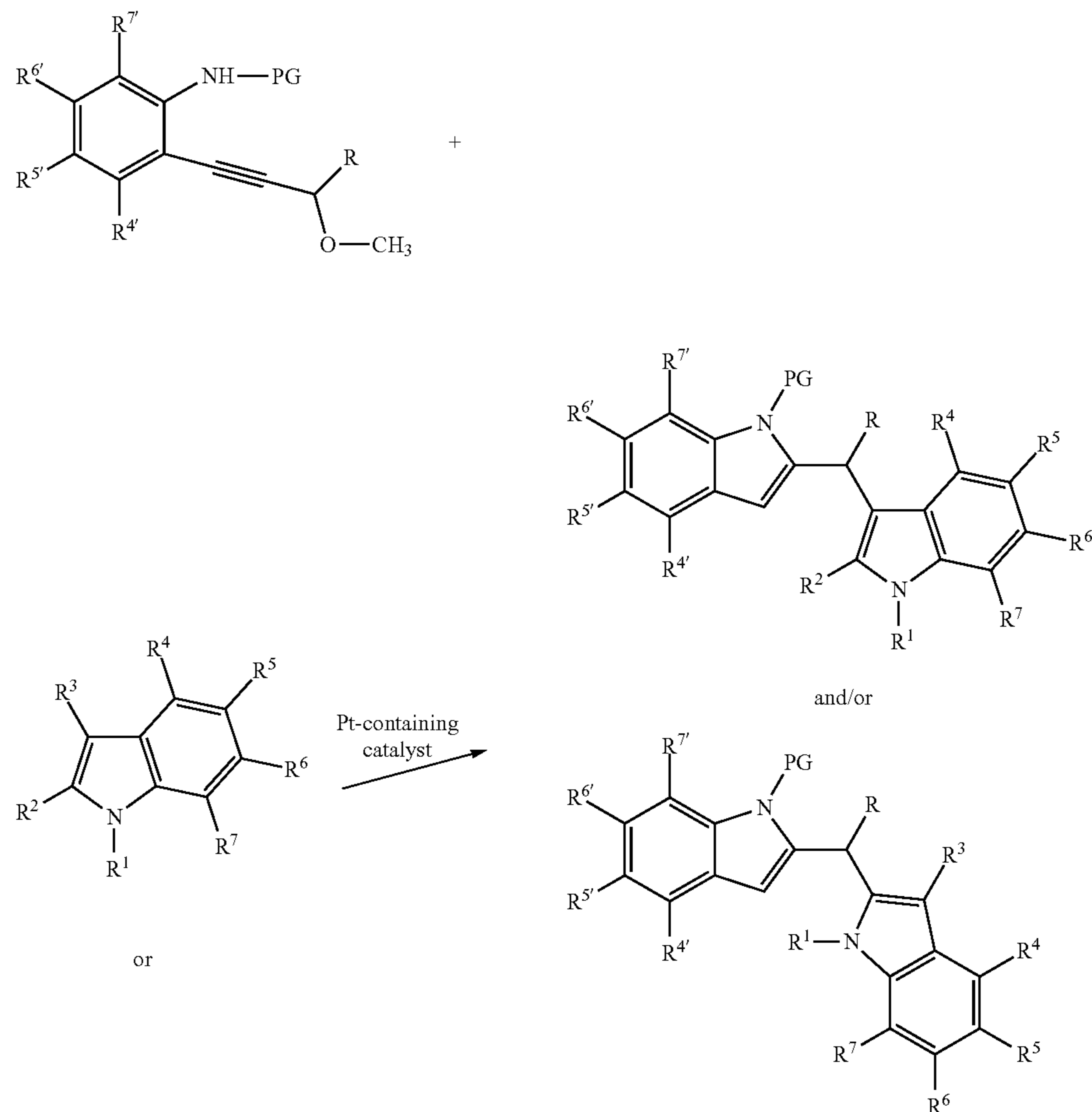
The method comprises contacting an ether comprising an arylpropargyl moiety with a substituted or unsubstituted indol and/or a substituted or unsubstituted pyrrole. When the arylpropargyl ether is contacted with an indole, the resulting product is a diindolylmethane. When the arylpropargyl ether is contacted with a pyrrole, the product is a 1-indolyl-1-pyrrolylmethane. The diindolylmethane or 1-indolyl-1-pyrrolylmethane products can be further reacted to yield the corresponding indolyl (or indolyl/pyrrolyl) carbazoles.

Thus, disclosed herein is a method to make diindolylmethanes and indolyl/pyrrolylmethanes, the method comprising:

contacting an ether comprising an arylpropargyl moiety and an amine-protected, substituted or unsubstituted aniline moiety with a substituted or unsubstituted indol or a substituted or unsubstituted pyrrole, in the presence of a metal-containing catalyst, for a time and at a temperature to cause an annulation/arylation cascade reaction that yields a diindolylmethane or a indolyl/pyrrolylmethane.

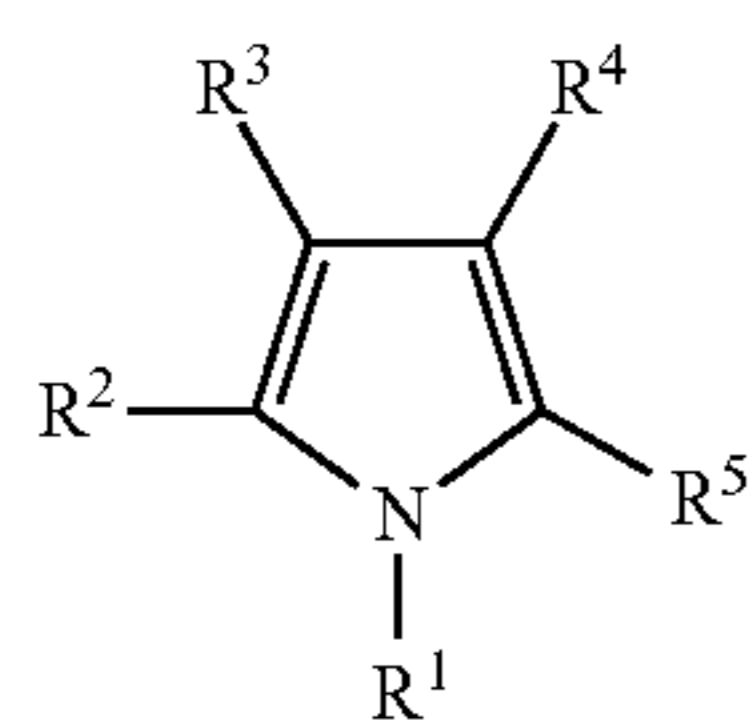
The method may comprise performing the reaction depicted in Reaction Scheme 1:

Reaction Scheme 1



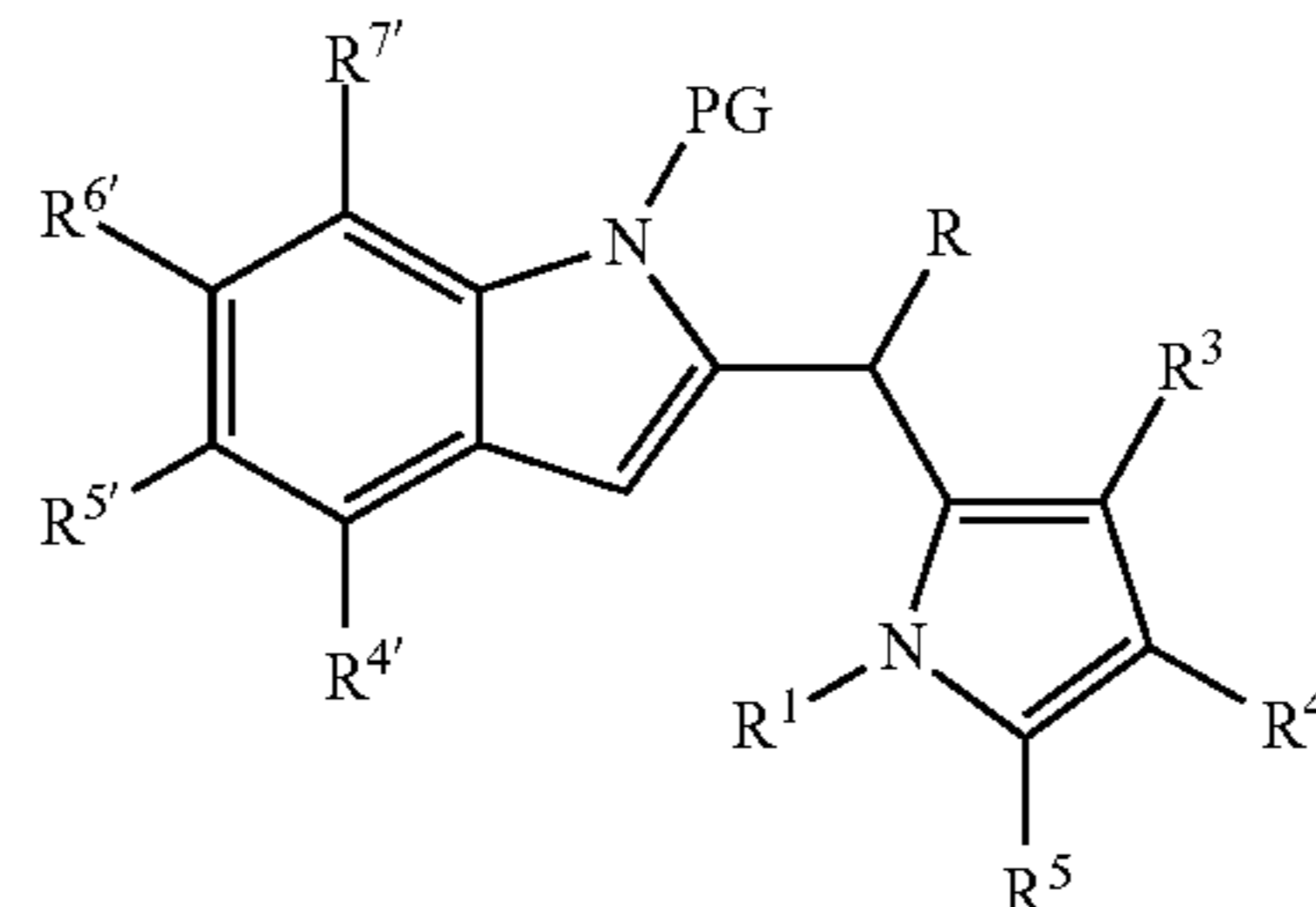
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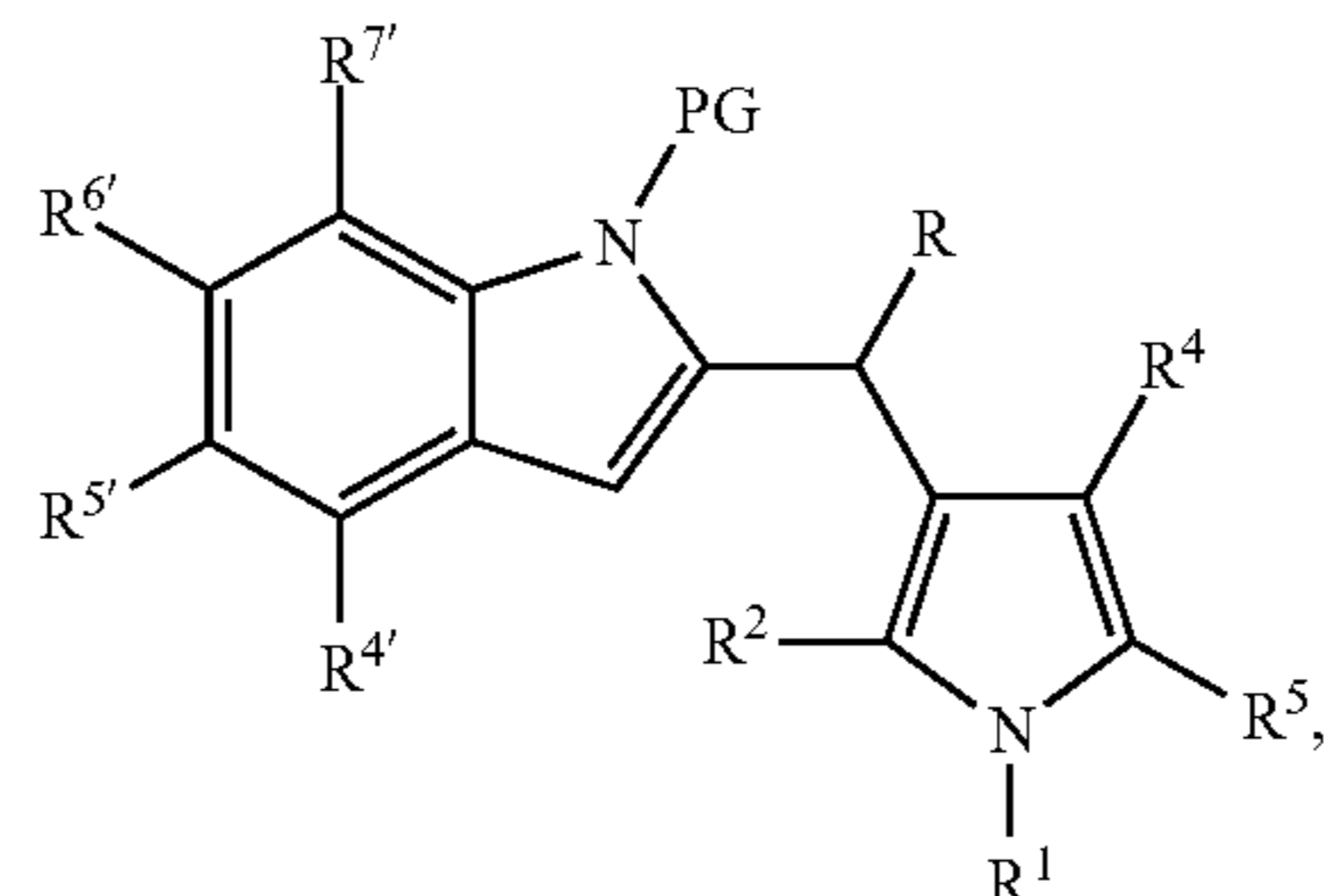


Pt-containing catalyst

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and/or



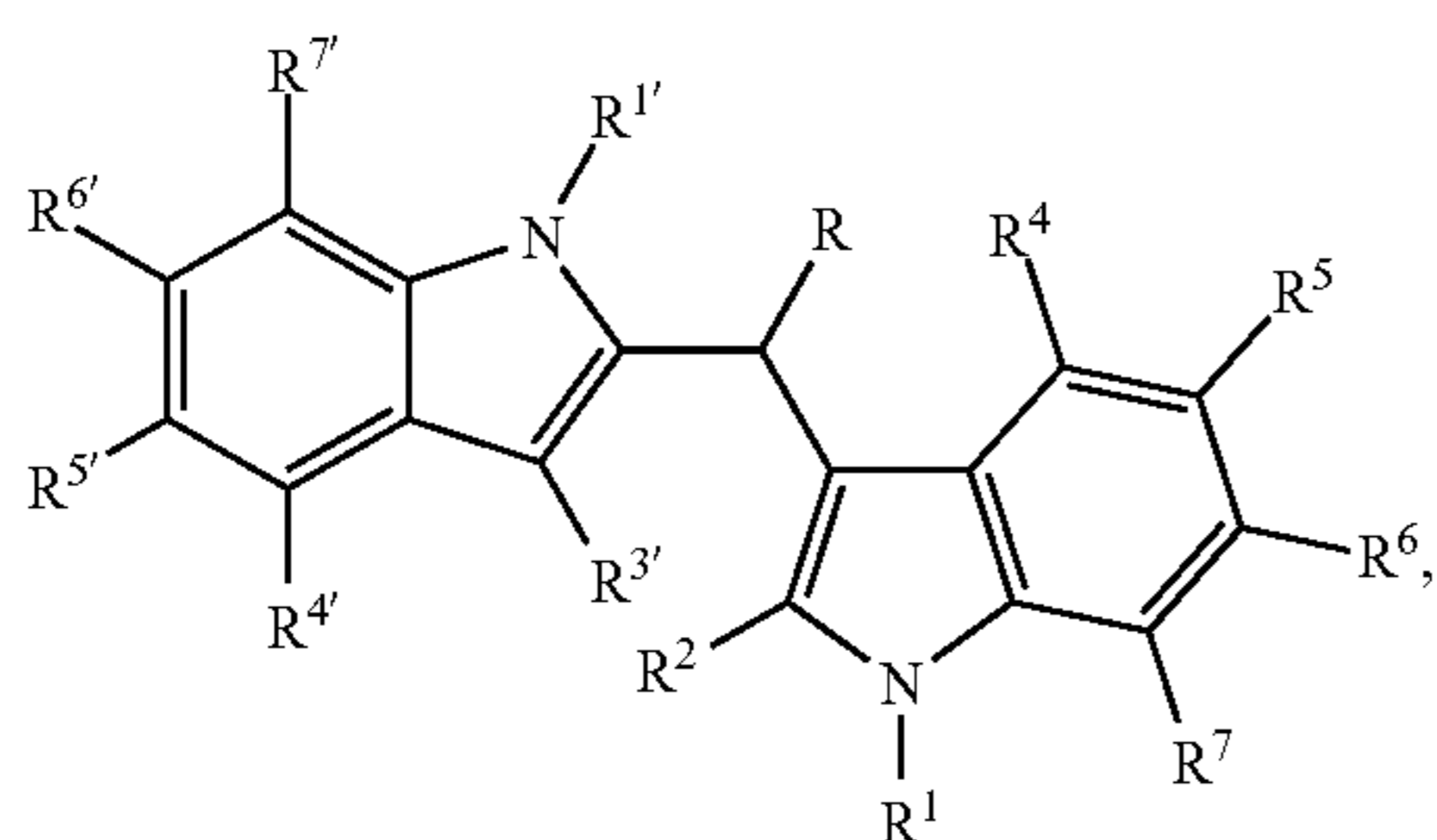
wherein each  $R^1$  is independently hydrogen or alkyl;

“PG” designates an amine protecting group; and

each  $R$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^{4'}$ ,  $R^{5'}$ ,  $R^{6'}$ , and  $R^{7'}$  is independently selected from hydrogen, halogen, hydroxyl, substituted or unsubstituted alkyl, substituted or unsubstituted alkoxy, substituted or unsubstituted cycloalkyl, substituted or unsubstituted aryl, substituted or unsubstituted arylalkyl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heteroarylalkyl, substituted or unsubstituted heterocyclyl, or substituted or unsubstituted heterocyclalkyl.

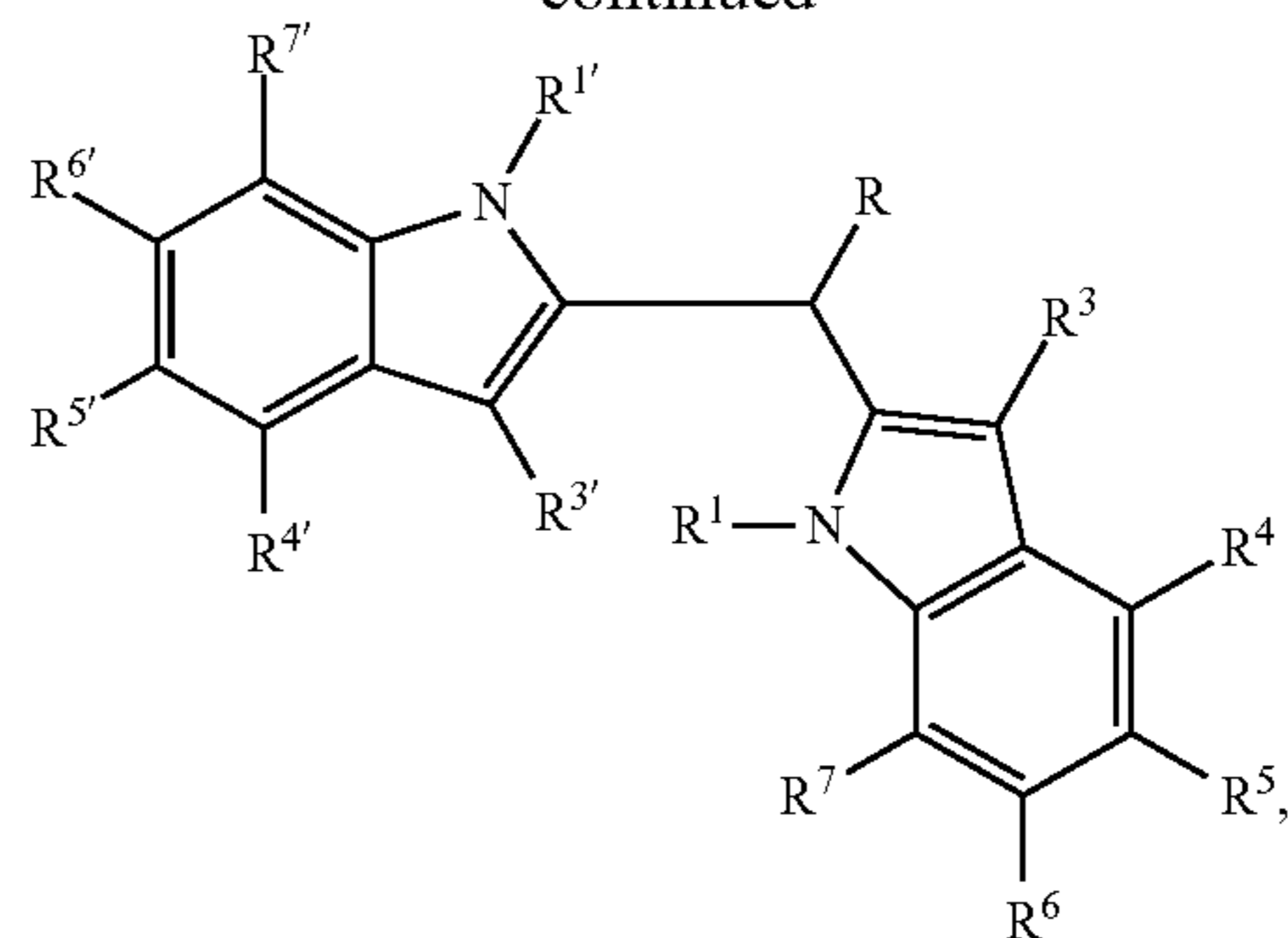
The catalyst may be a catalyst containing a noble metal (ruthenium, rhodium, palladium, silver, osmium, iridium, platinum, and gold), preferably a platinum-containing catalyst or a rhodium-containing catalyst, and most preferably  $PtCl_2$ .

Also disclosed herein is a pharmaceutical composition comprising an amount of a compound selected from the group consisting of:

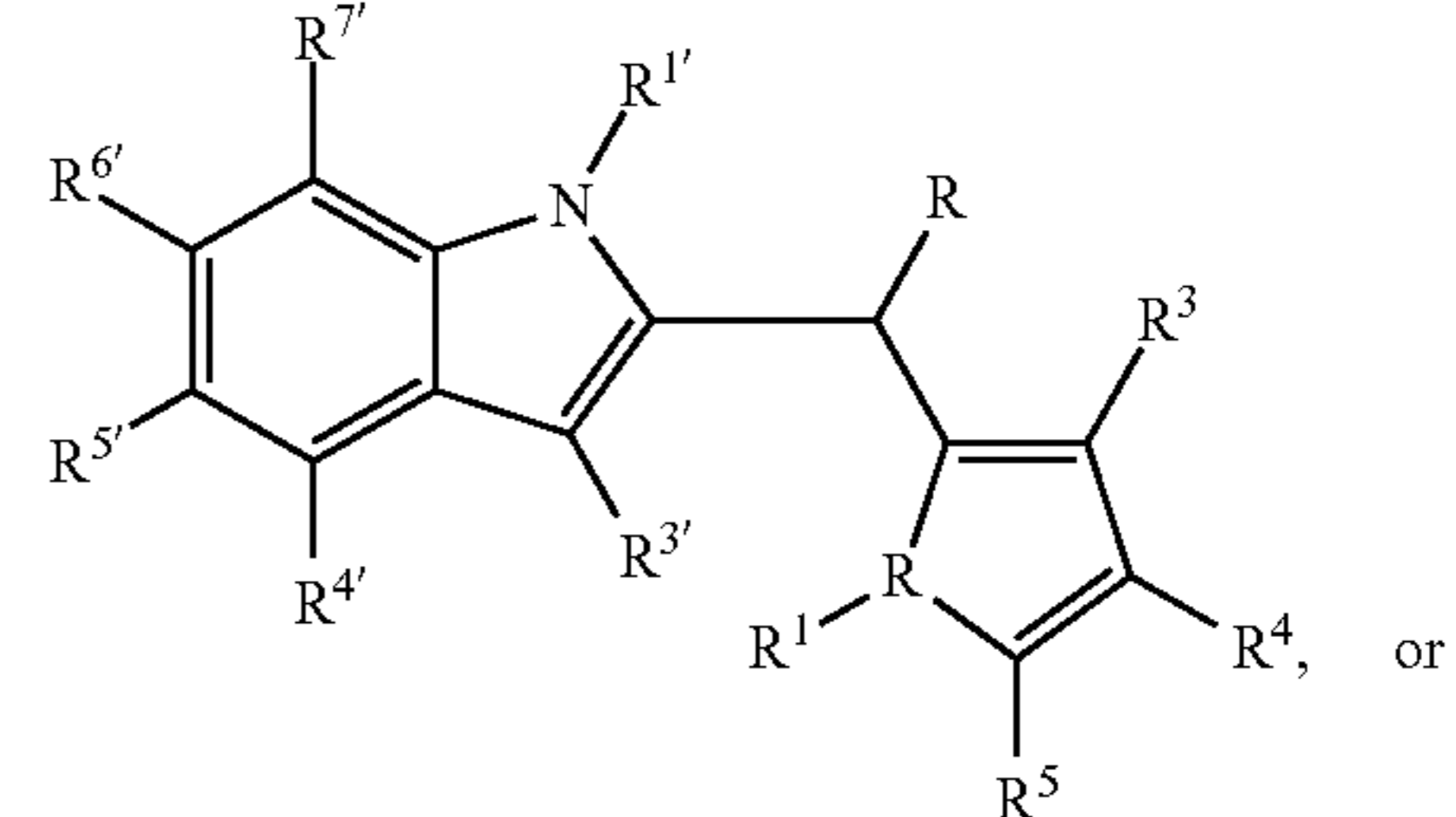


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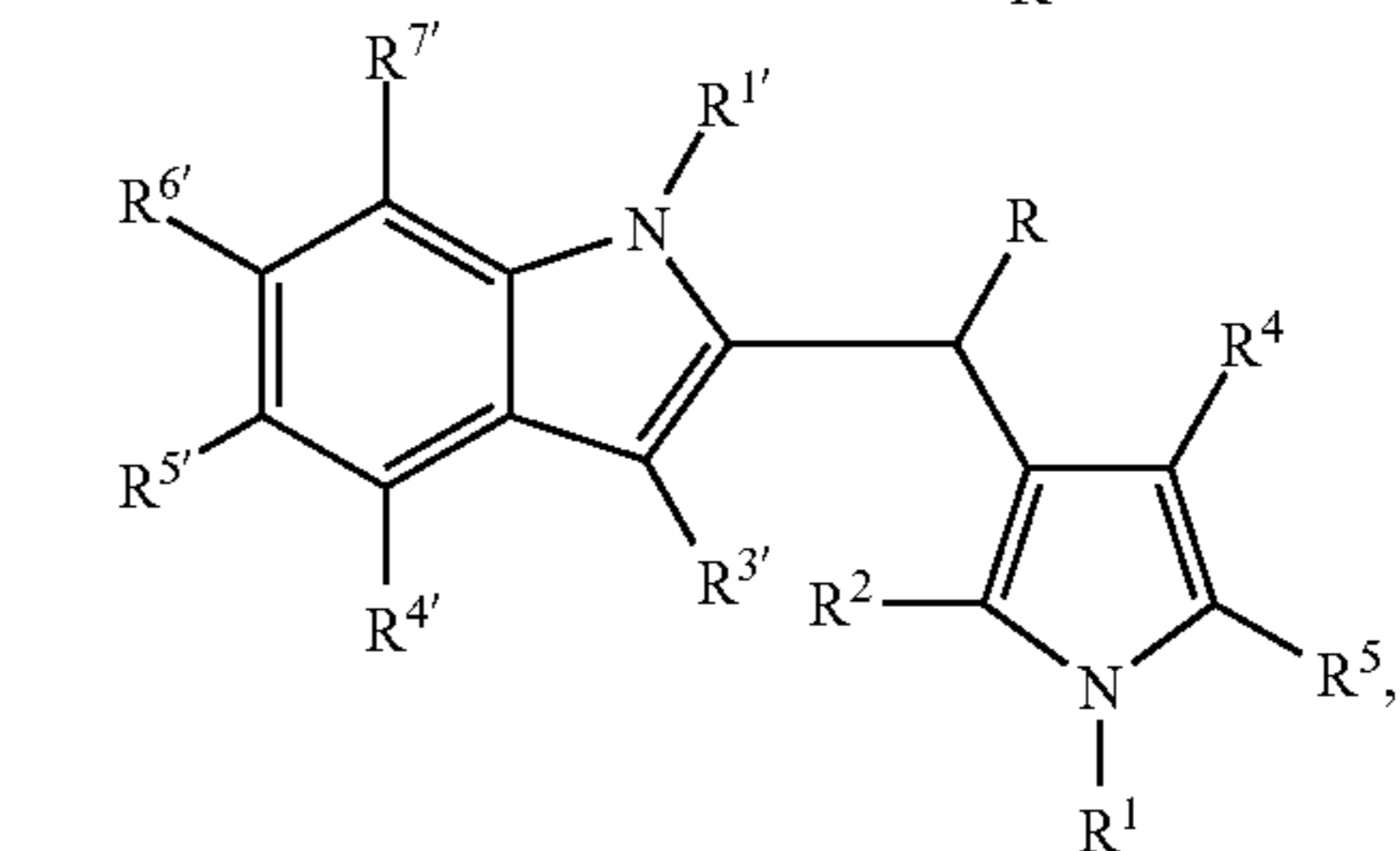


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wherein each  $R^1$  and  $R^{1'}$  is independently hydrogen or alkyl; and

each  $R$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^{3'}$ ,  $R^{4'}$ ,  $R^{5'}$ ,  $R^{6'}$ , and  $R^{7'}$  is independently selected from hydrogen, halogen, hydroxyl, substituted or unsubstituted alkyl, substituted or unsubstituted alkoxy, substituted or unsubstituted cycloalkyl, sub-

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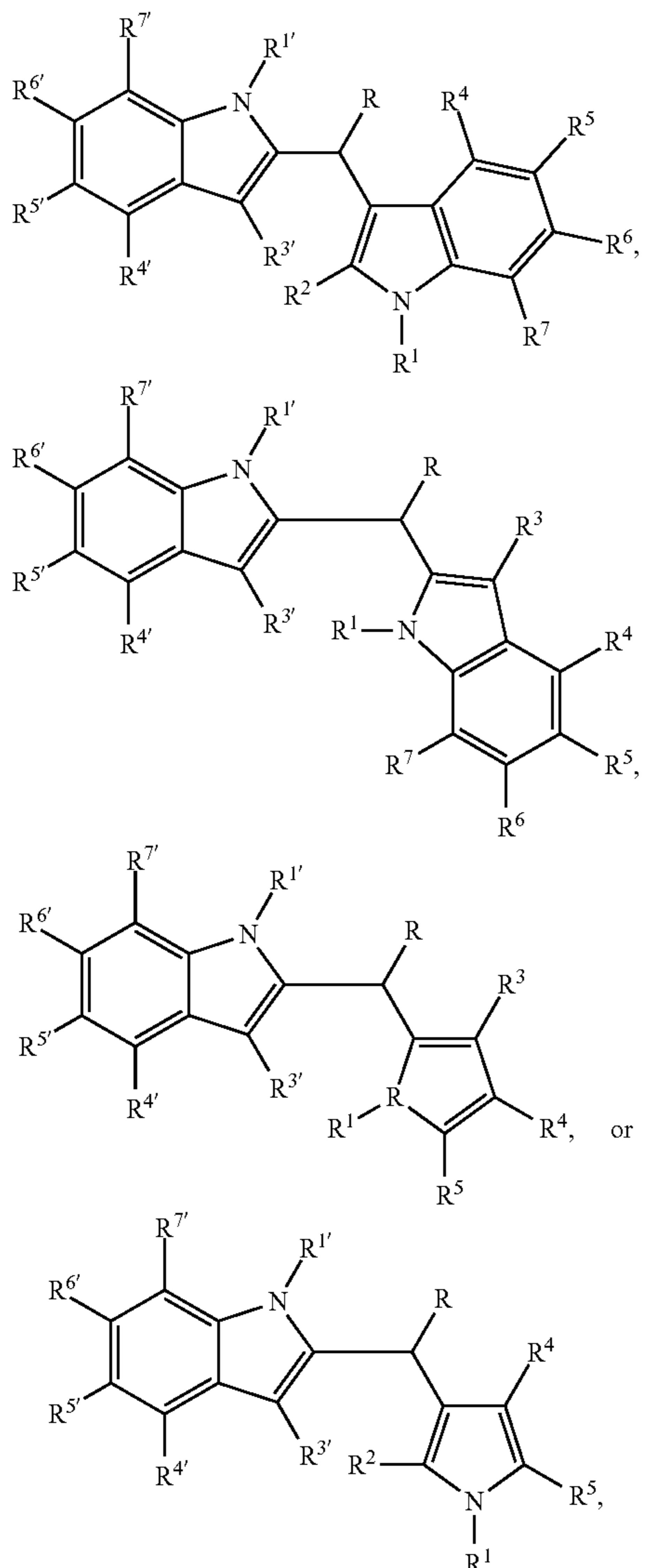
stituted or unsubstituted aryl, substituted or unsubstituted arylalkyl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heteroarylalkyl, substituted or unsubstituted heterocyclyl, or substituted or unsubstituted heterocyclylalkyl;

or a pharmaceutically suitable salt thereof;

in combination with a pharmaceutically suitable carrier;

wherein the amount is effective to modulate activity of arylhydrocarbon receptors in mammals, or the amount is effective to inhibit activity of PCSK9 in mammals, or the amount is effective to stimulate secretion of glucagon-like peptide 1 in mammals.

Further disclosed herein is a method to modulate activity of arylhydrocarbon receptors in mammals, the method comprising administering to the mammal a arylhydrocarbon receptor modulating-effective amount of a compound selected from the group consisting of



wherein each R<sup>1</sup> and R<sup>1'</sup> is independently hydrogen or alkyl; and

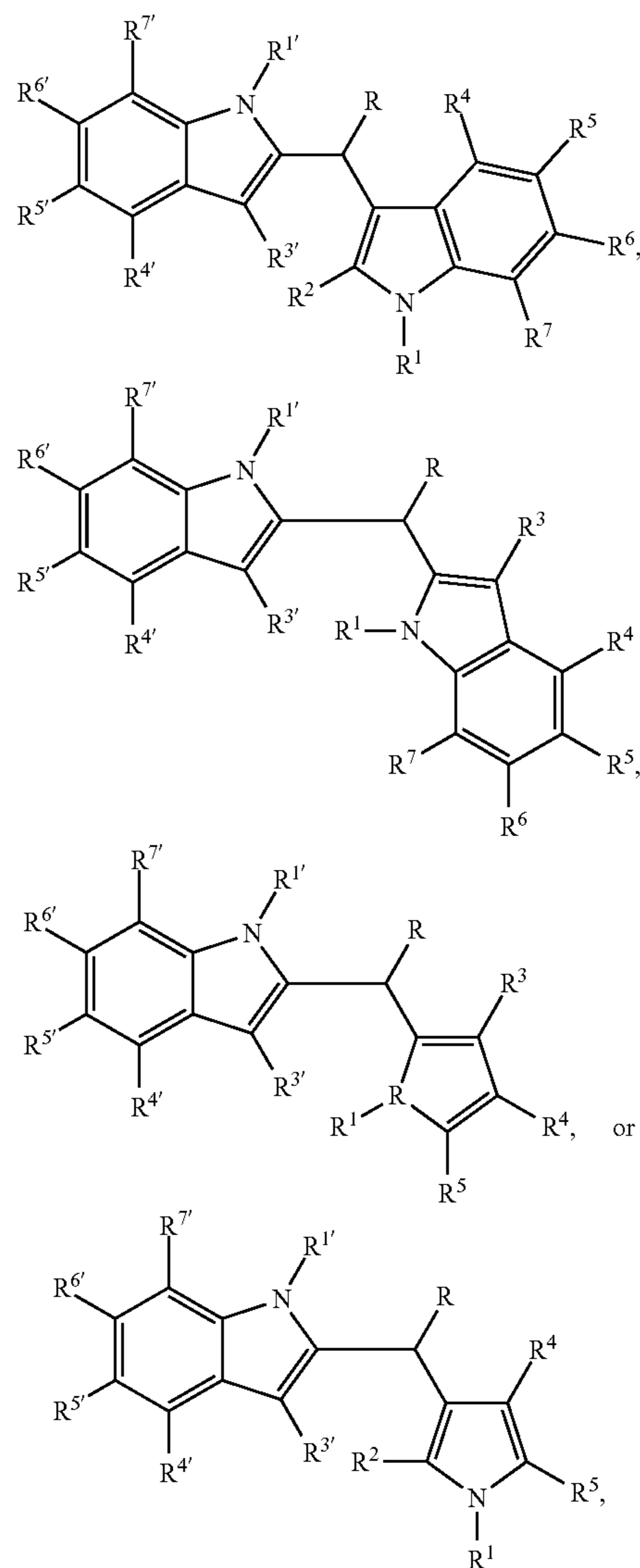
each R, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>3'</sup>, R<sup>4'</sup>, R<sup>5'</sup>, R<sup>6'</sup>, and R<sup>7'</sup> is independently selected from hydrogen, halogen, hydroxyl, substituted or unsubstituted alkyl, substituted or unsubstituted

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tuted alkoxy, substituted or unsubstituted cycloalkyl, substituted or unsubstituted aryl, substituted or unsubstituted arylalkyl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heteroarylalkyl, substituted or unsubstituted heterocyclyl, or substituted or unsubstituted heterocyclylalkyl;

or a pharmaceutically suitable salt thereof.

Additionally disclosed herein is a method to inhibit activity of proprotein convertase subtilisin/kexin type 9 (PCSK9) in mammals, the method comprising administering to the mammal an PCSK9 inhibitory-effective amount of a compound selected from the group consisting of



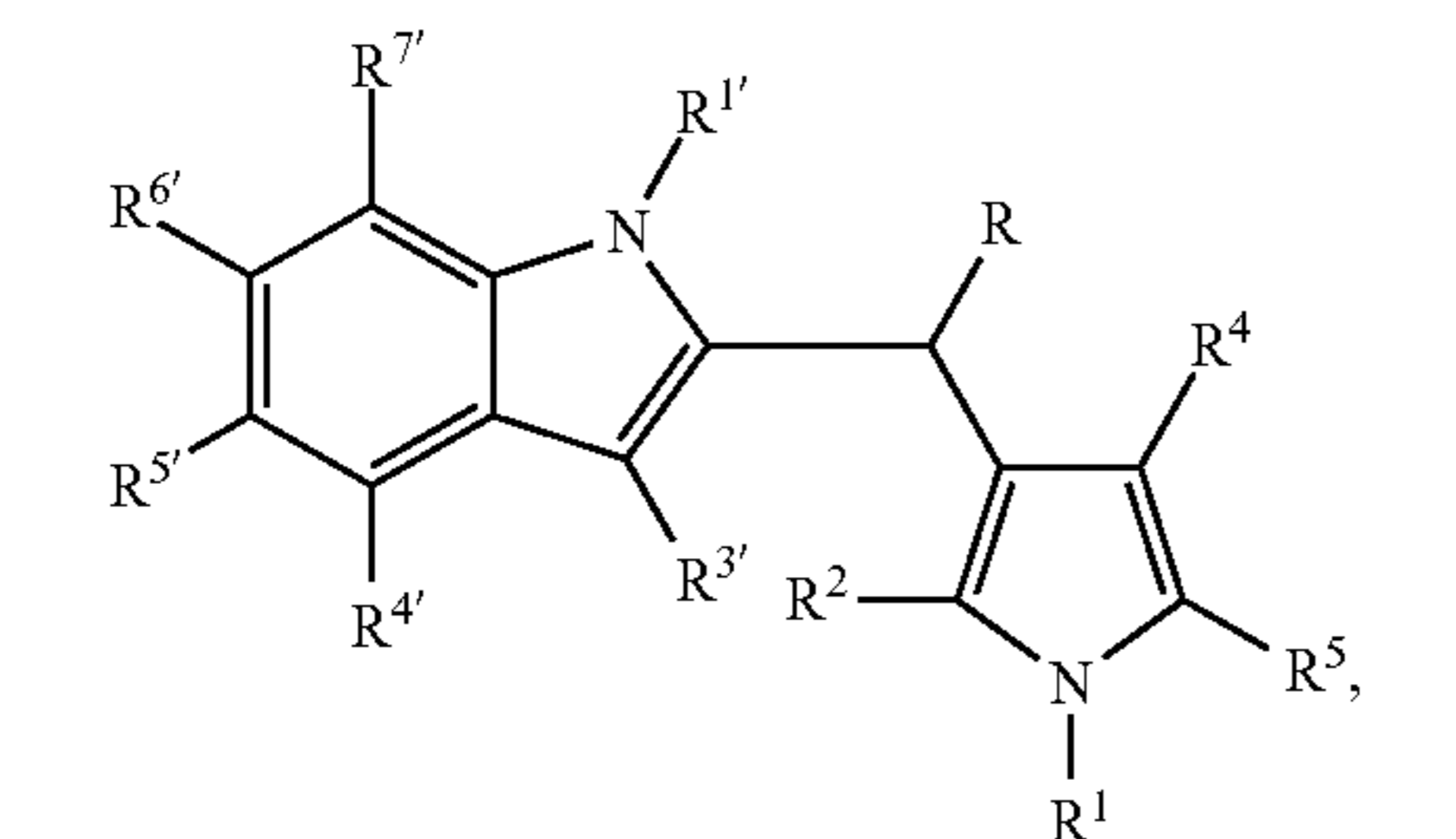
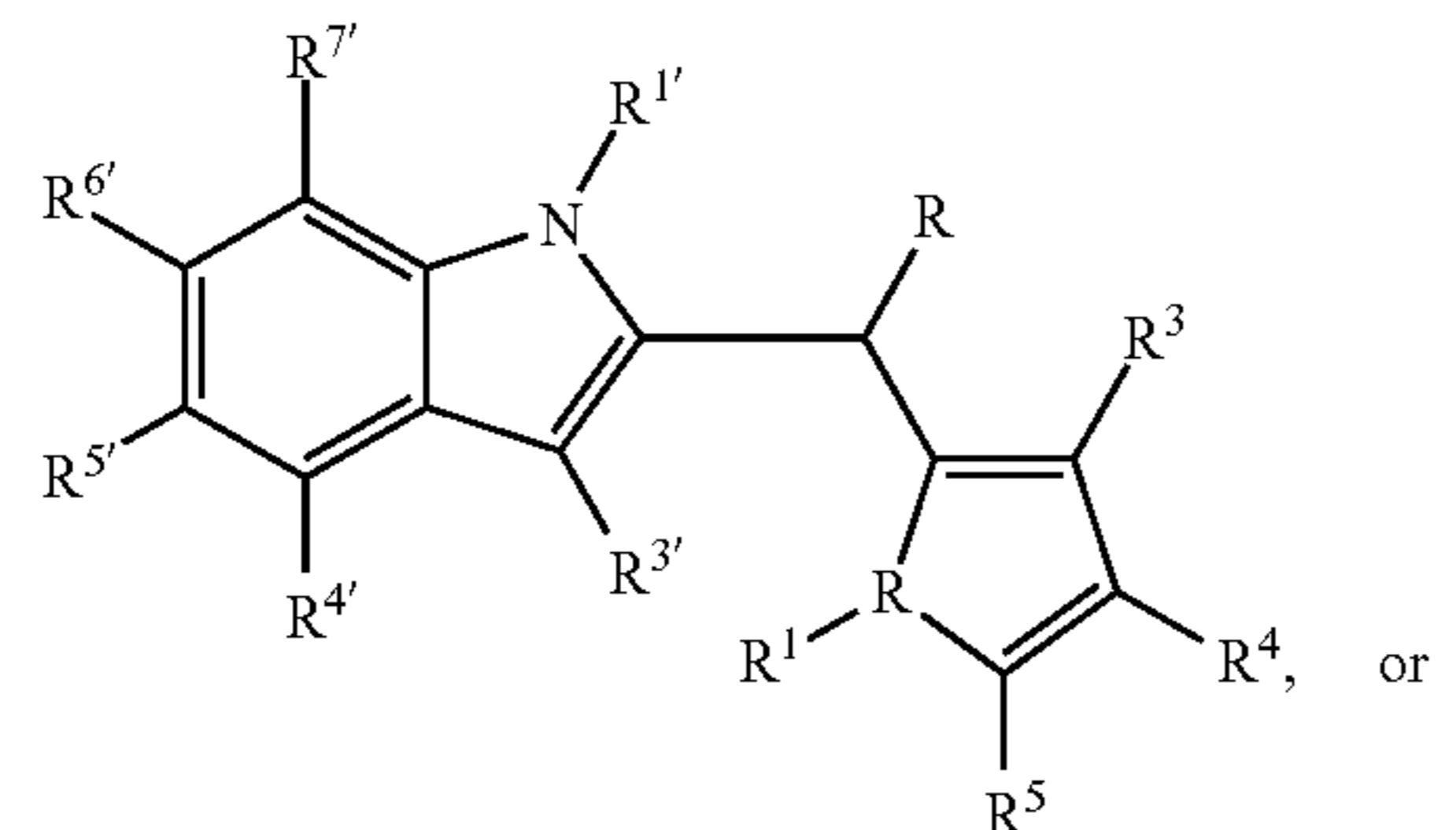
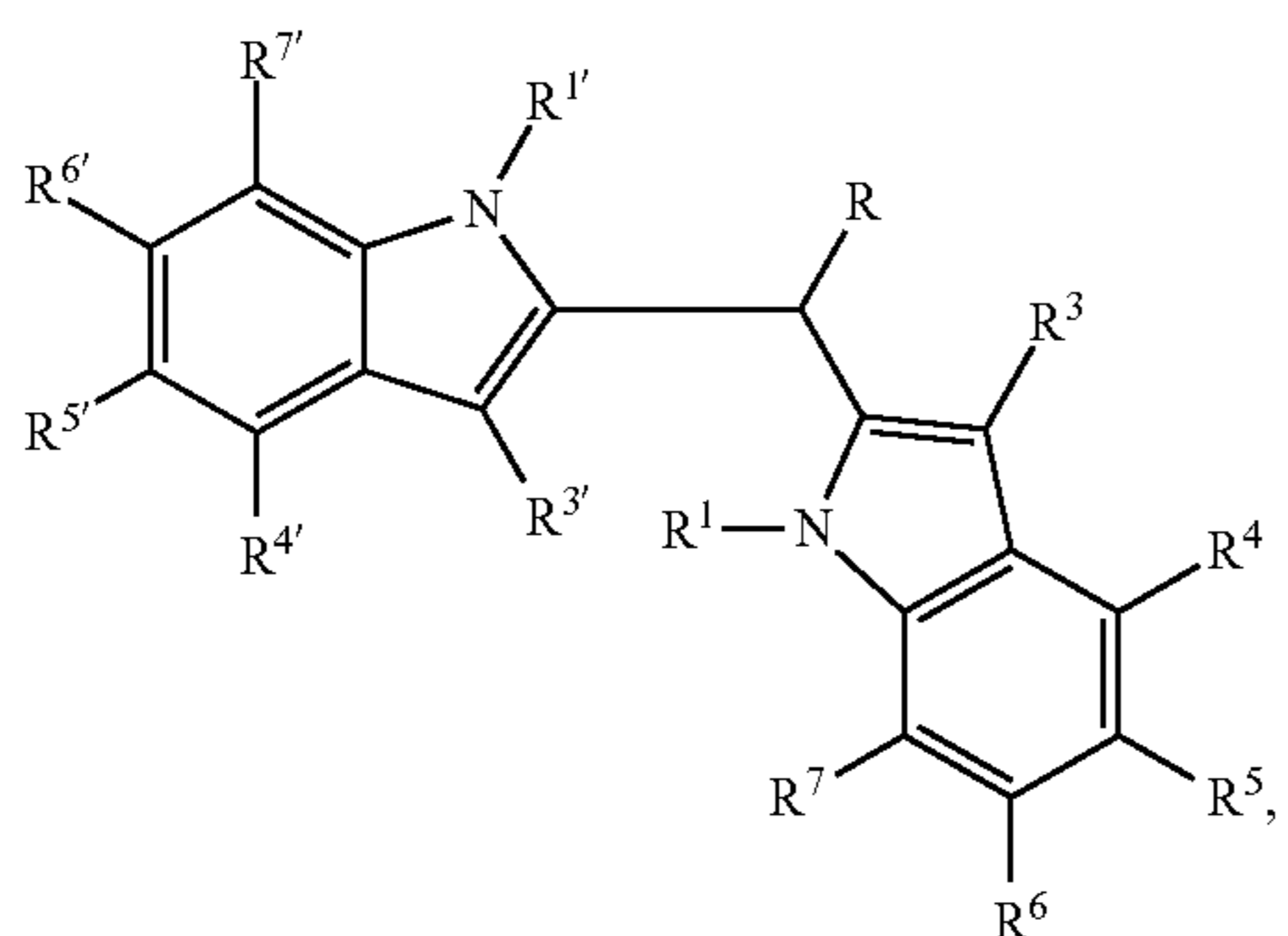
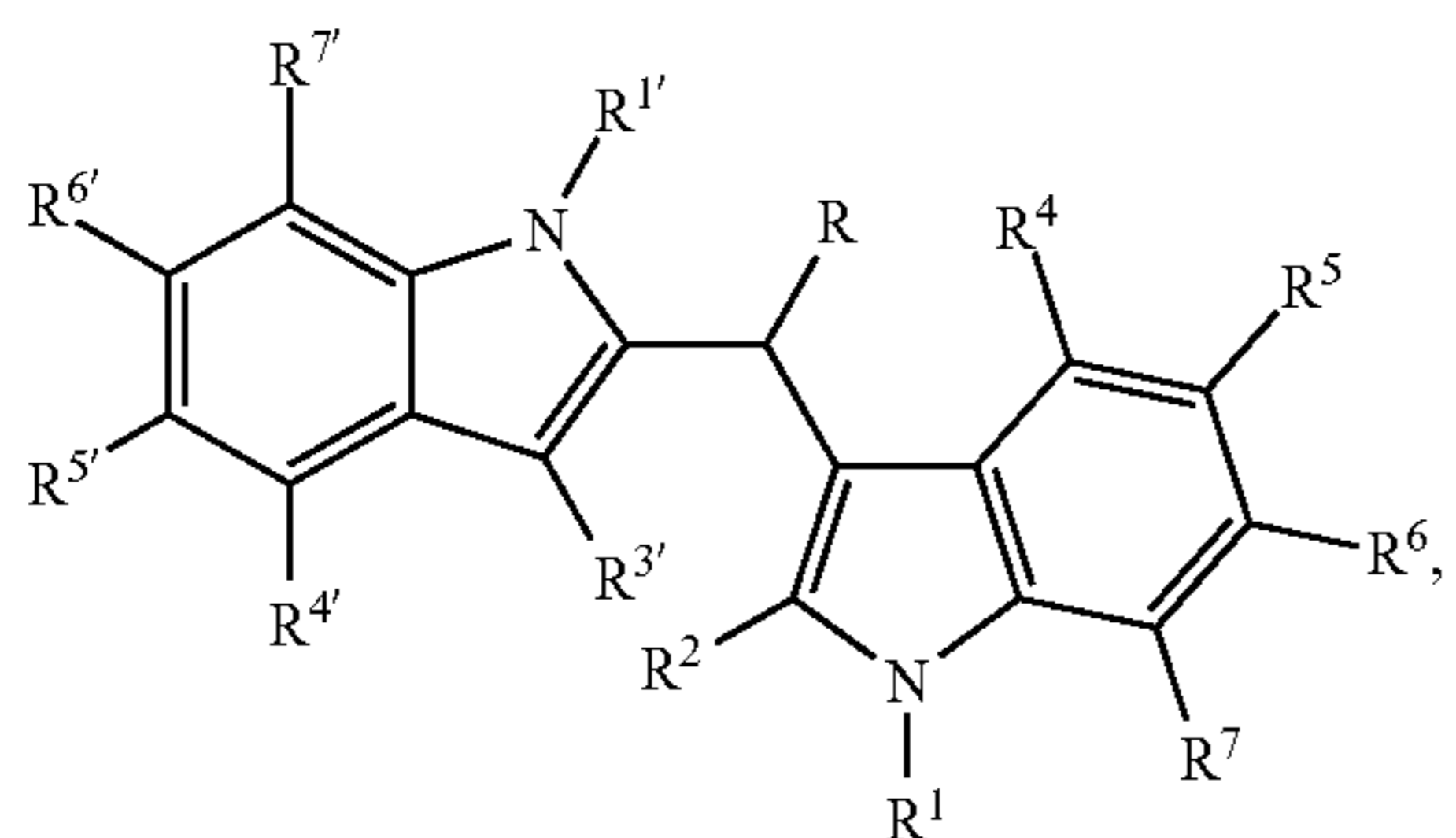
wherein each R<sup>1</sup> and R<sup>1'</sup> is independently hydrogen or alkyl; and

each R, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>3'</sup>, R<sup>4'</sup>, R<sup>5'</sup>, R<sup>6'</sup>, and R<sup>7'</sup> is independently selected from hydrogen, halogen, hydroxyl, substituted or unsubstituted alkyl, substituted or unsubstituted alkoxy, substituted or unsubstituted cycloalkyl, substituted or unsubstituted aryl, substituted or unsubstituted arylalkyl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heteroarylalkyl, substituted or unsubstituted heterocyclyl, or substituted or unsubstituted heterocyclylalkyl;

or a pharmaceutically suitable salt thereof.

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Yet further disclosed is a method to stimulate secretion of glucagon-like peptide 1 (GLP-1) in mammals, the method comprising administering to the mammal a GLP-1 secretion-effective amount of a compound selected from the group consisting of



wherein each  $R^1$  and  $R^{1'}$  is independently hydrogen or alkyl; and

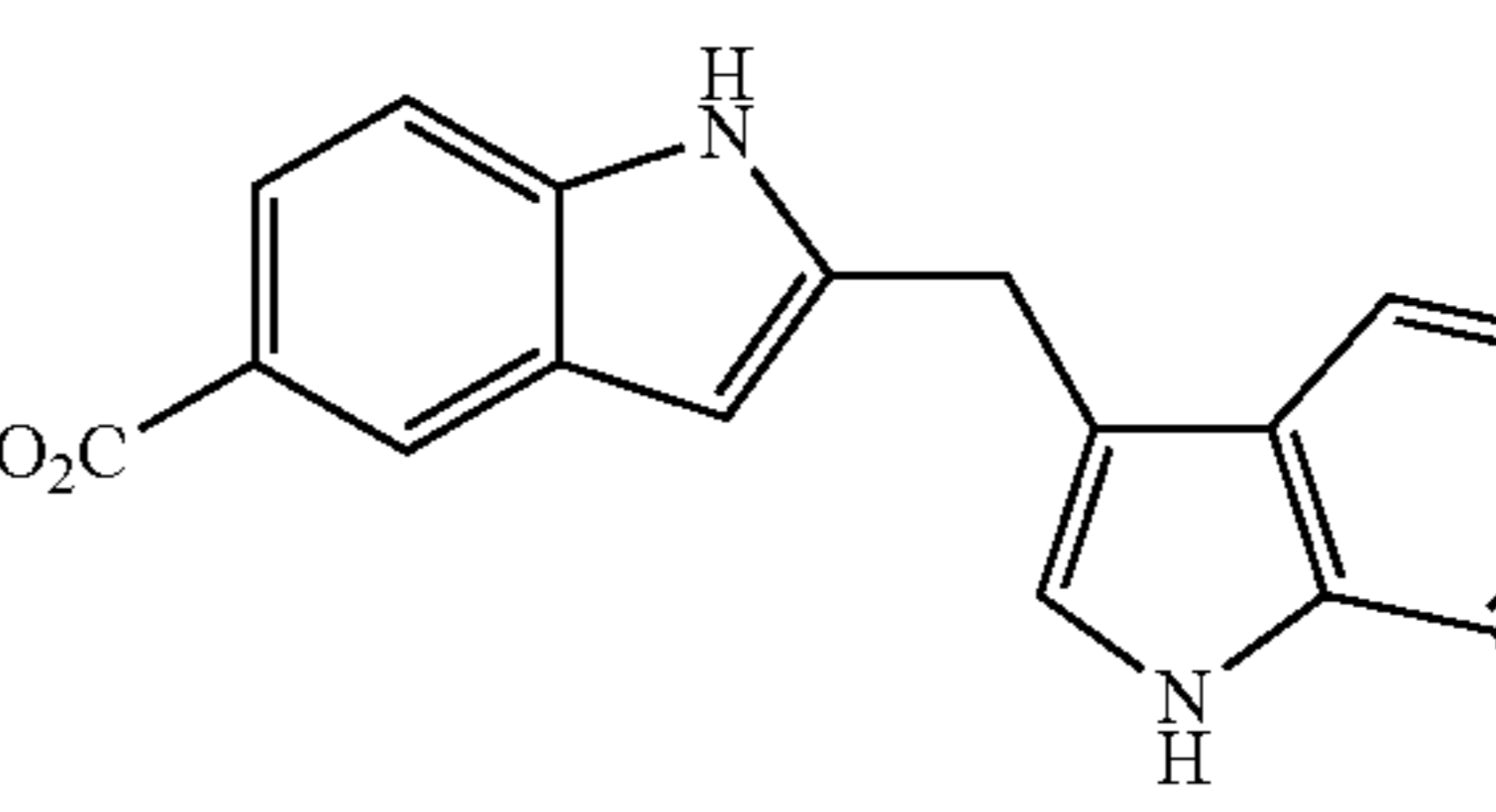
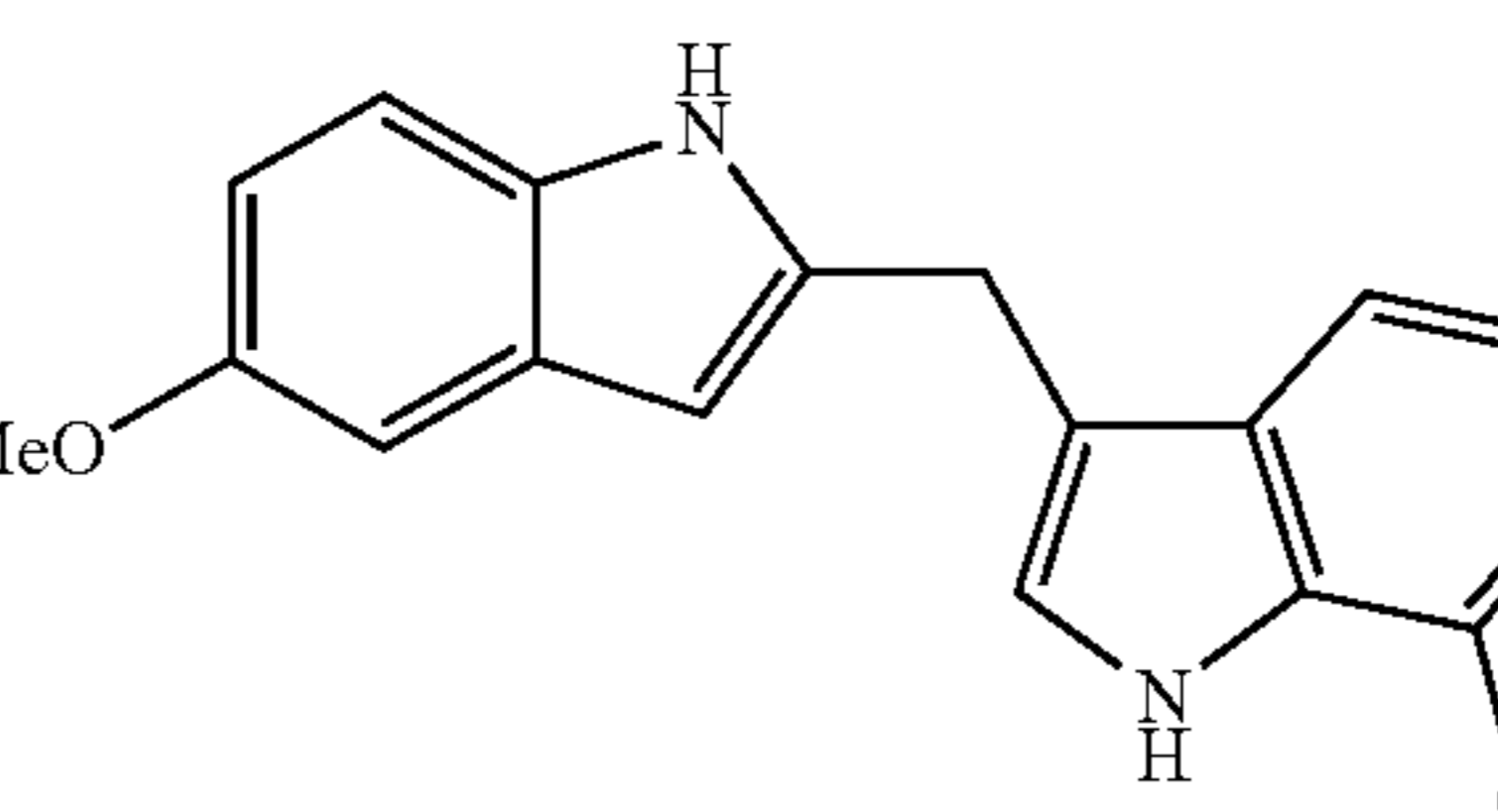
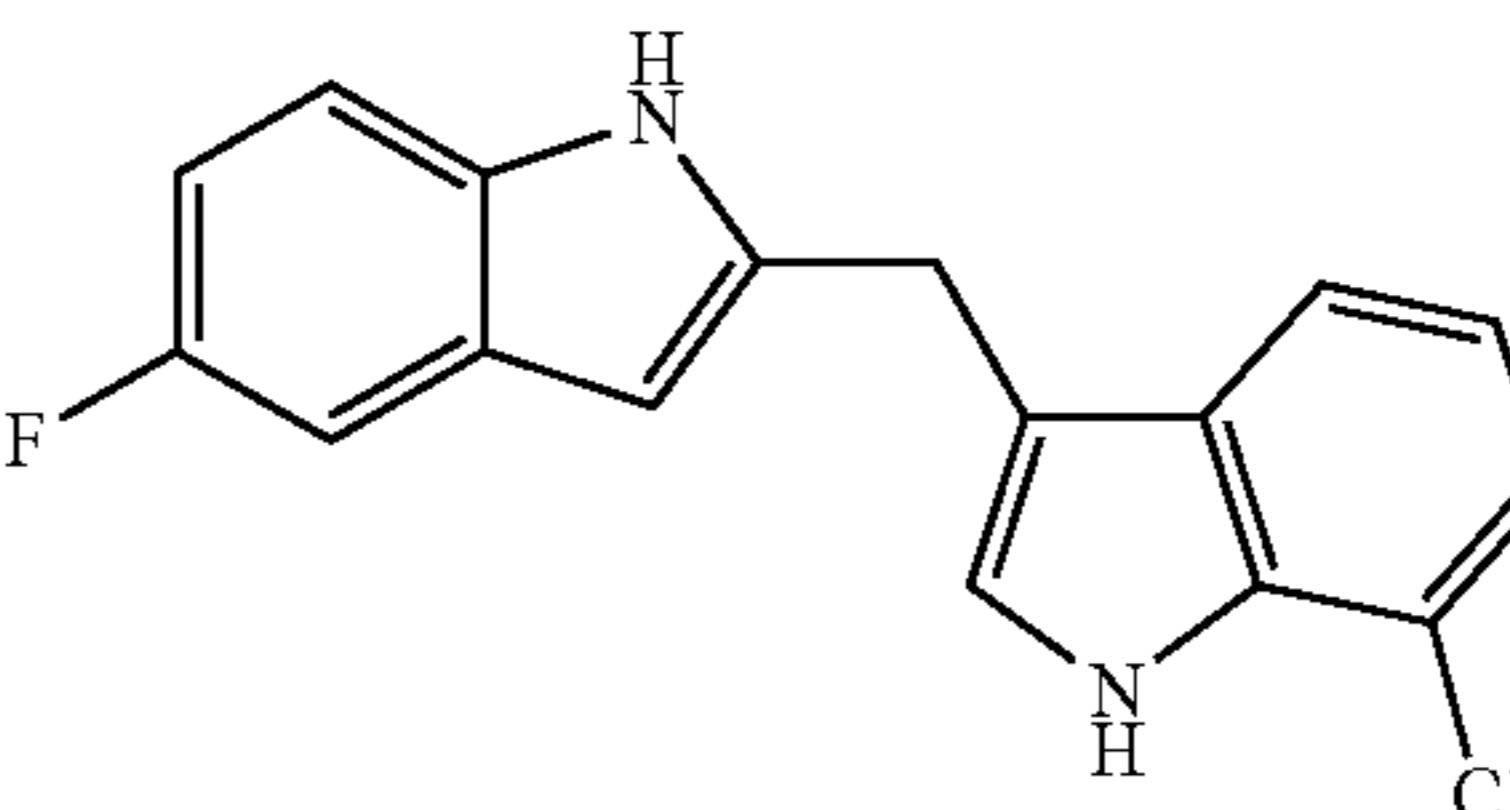
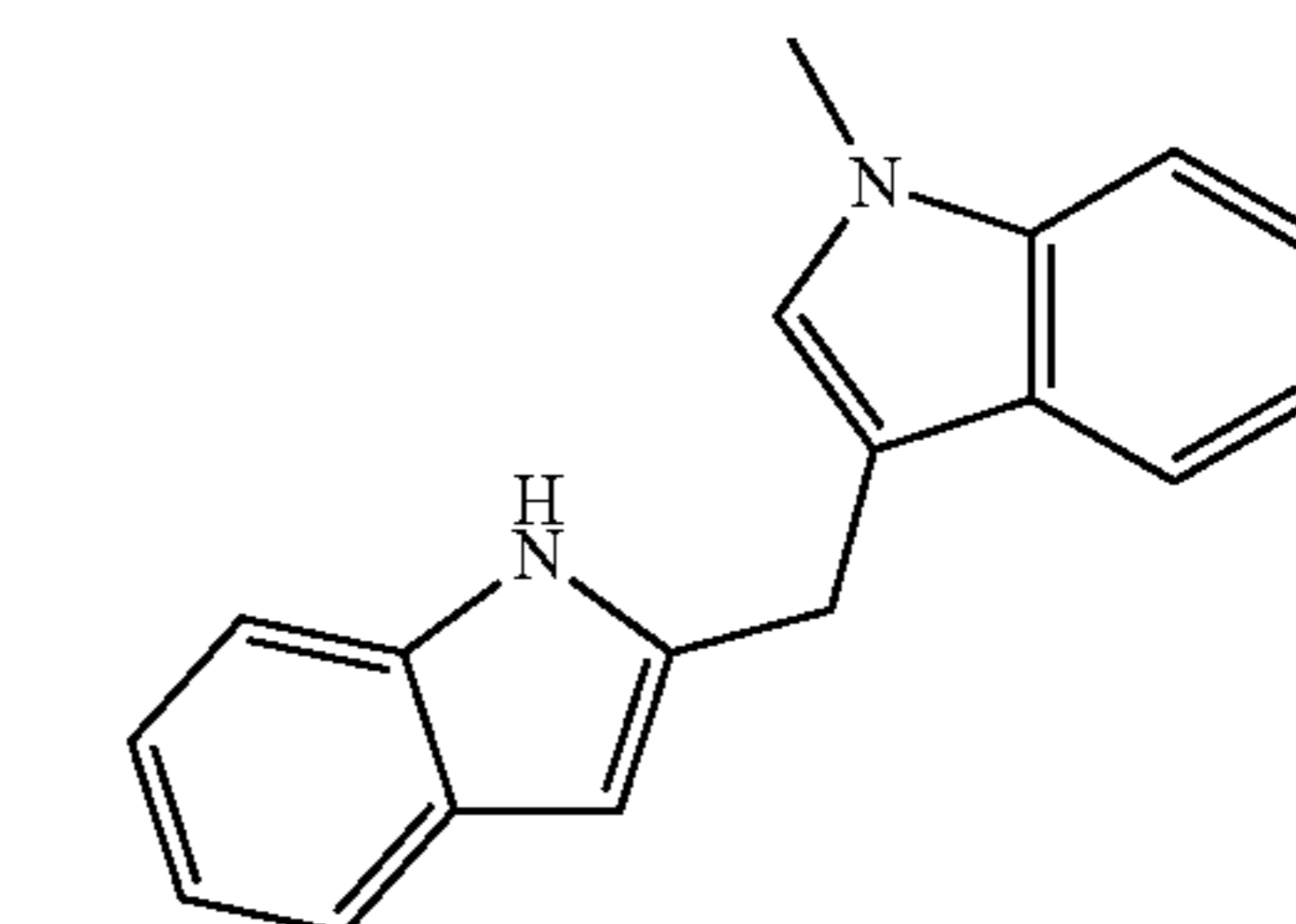
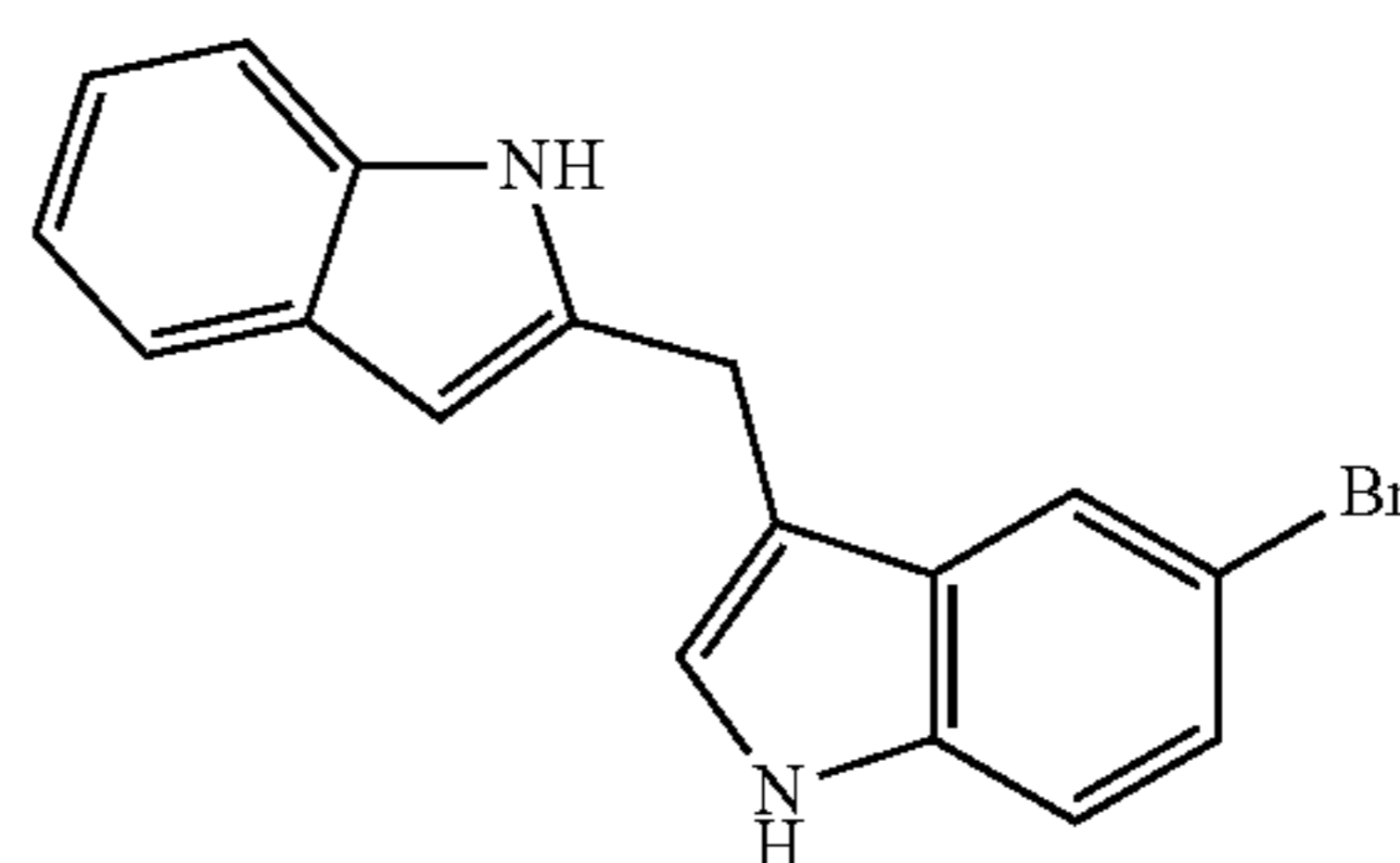
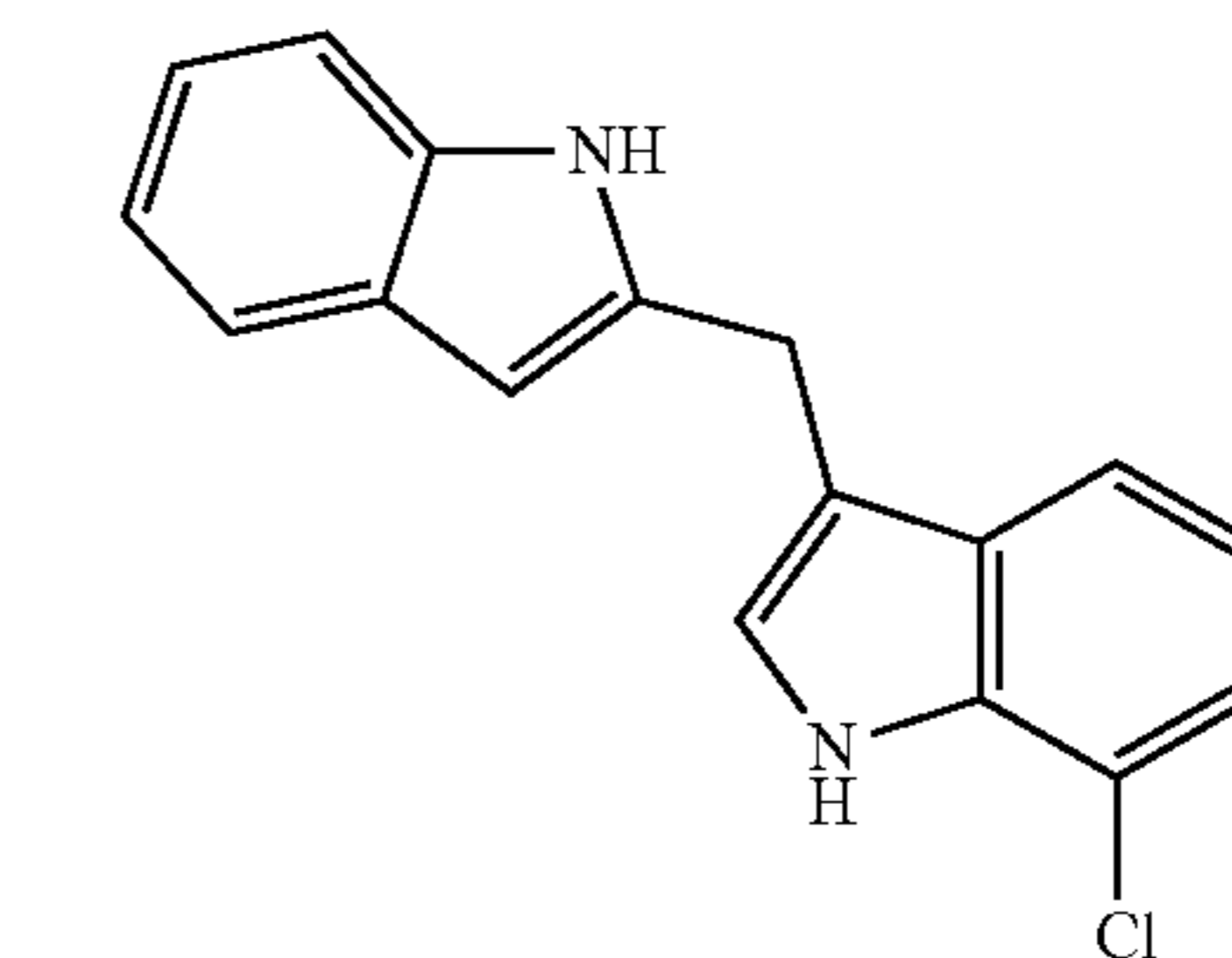
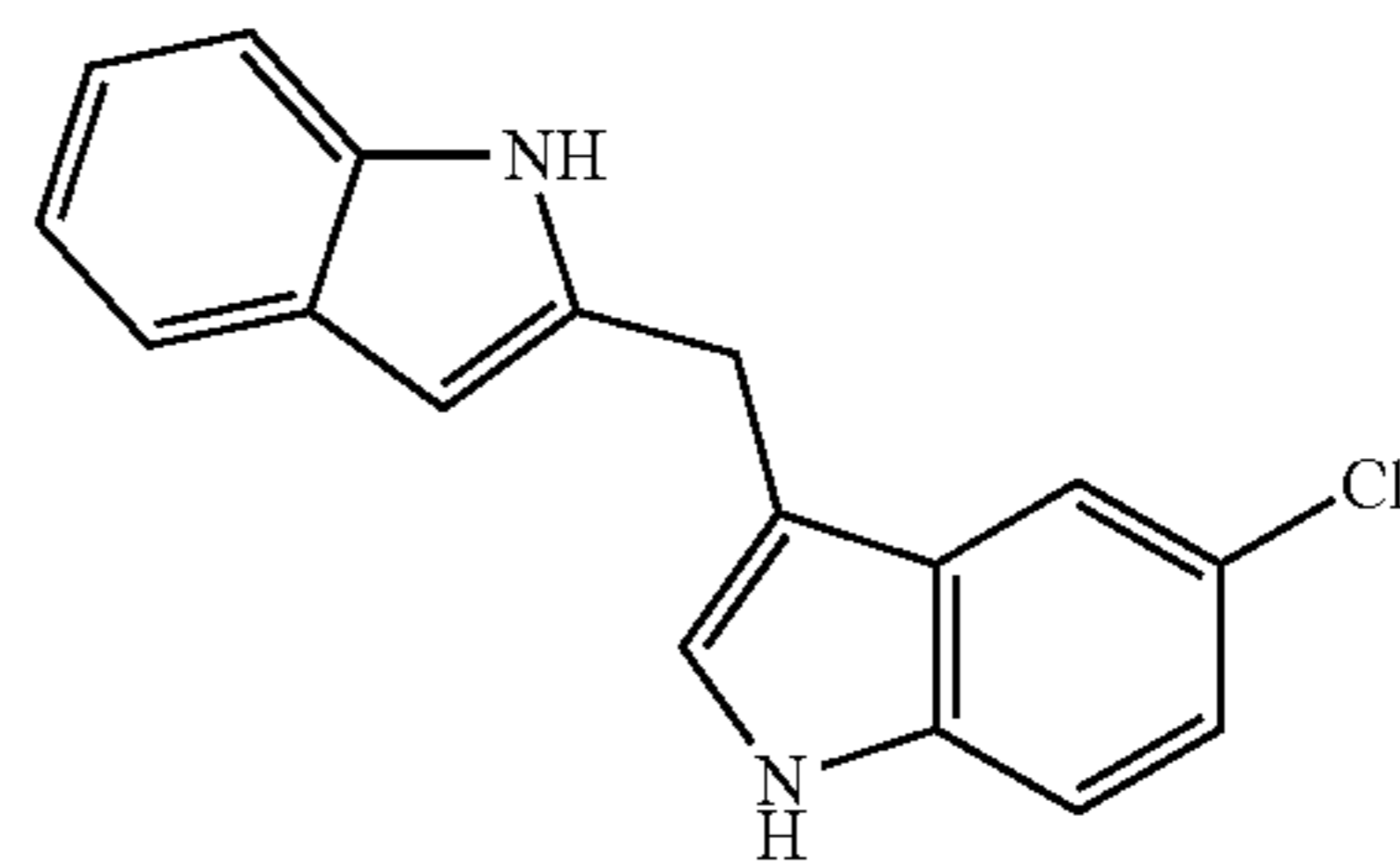
each  $R$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^{3'}$ ,  $R^{4'}$ ,  $R^{5'}$ ,  $R^{6'}$ , and  $R^{7'}$  is independently selected from hydrogen, halogen, hydroxyl, substituted or unsubstituted alkyl, substituted or unsubstituted alkoxy, substituted or unsubstituted cycloalkyl, substituted or unsubstituted aryl, substituted or unsubstituted arylalkyl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heteroarylalkyl, substituted or unsubstituted heterocyclyl, or substituted or unsubstituted heterocyclal-

l-alkyl;

or a pharmaceutically suitable salt thereof.

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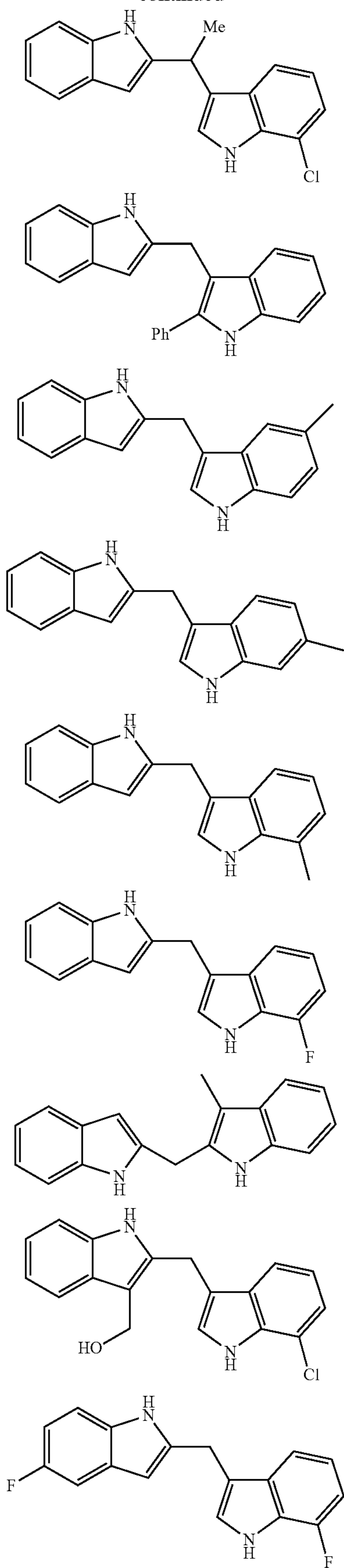
Exemplary compounds of the invention include:





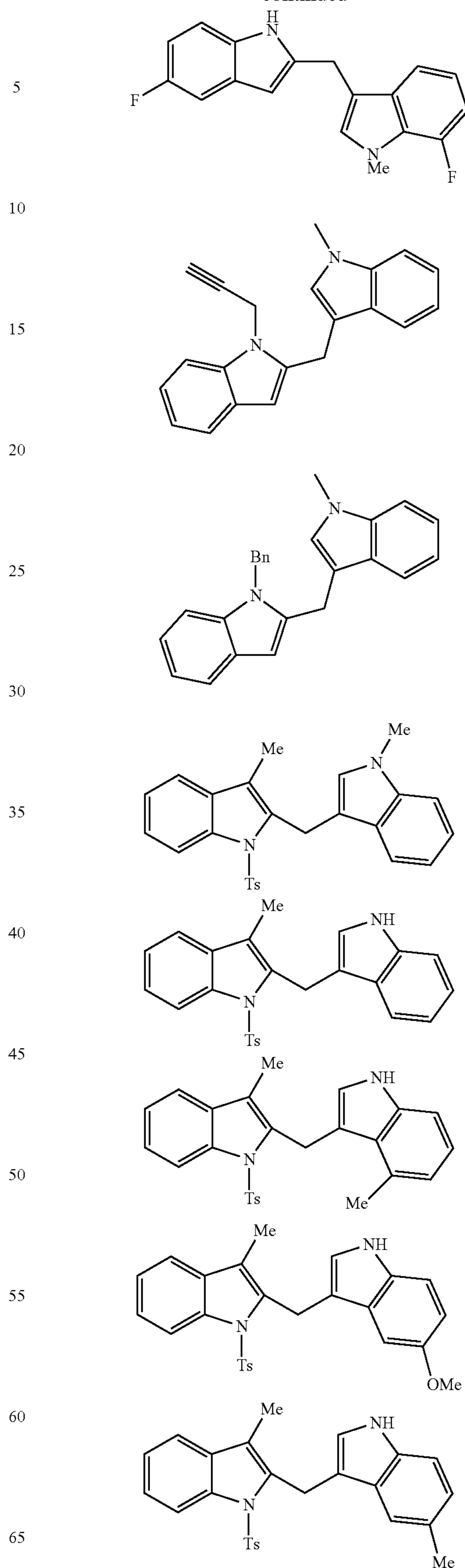
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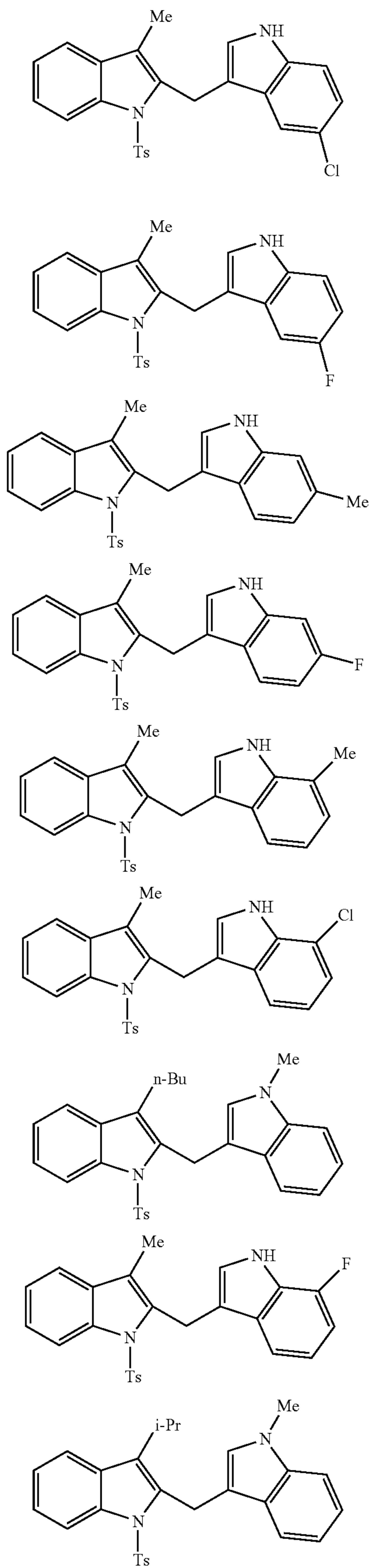
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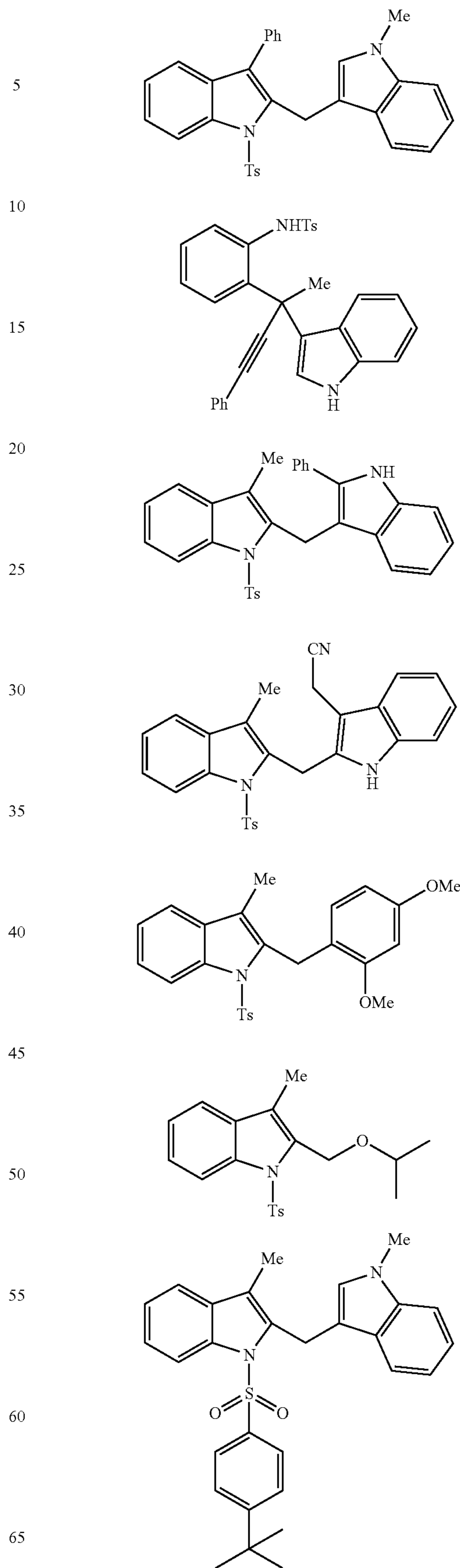
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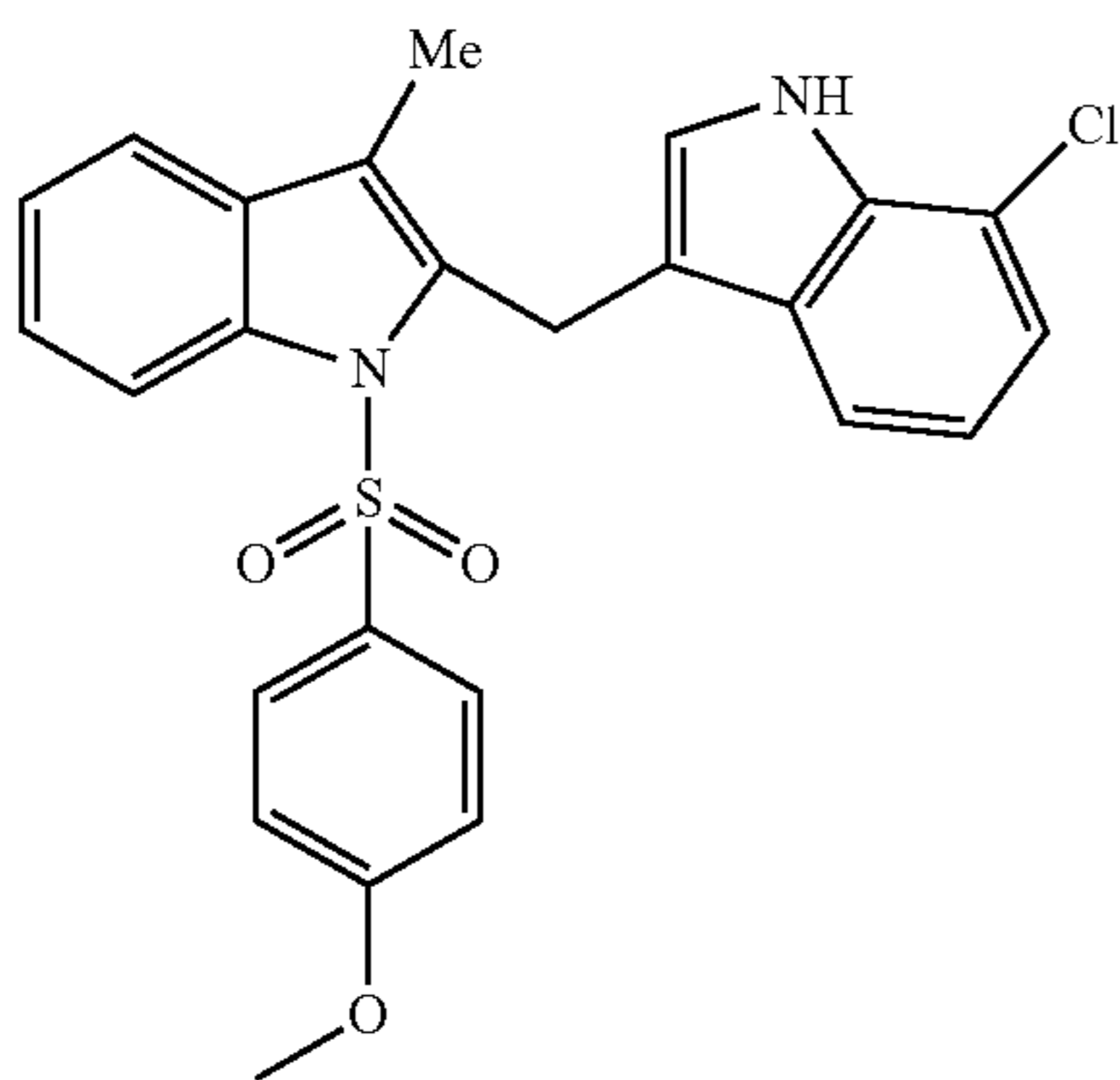
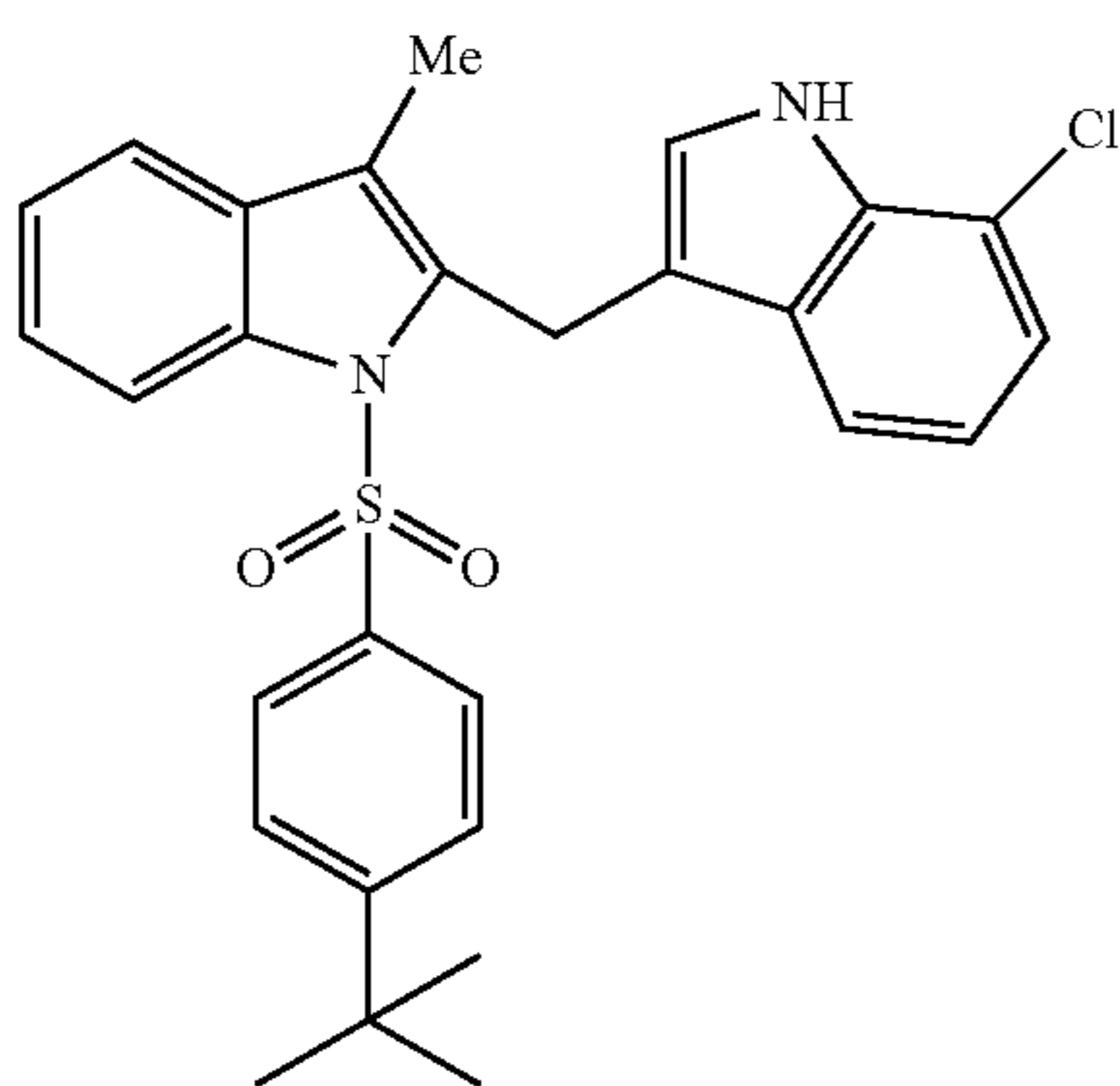
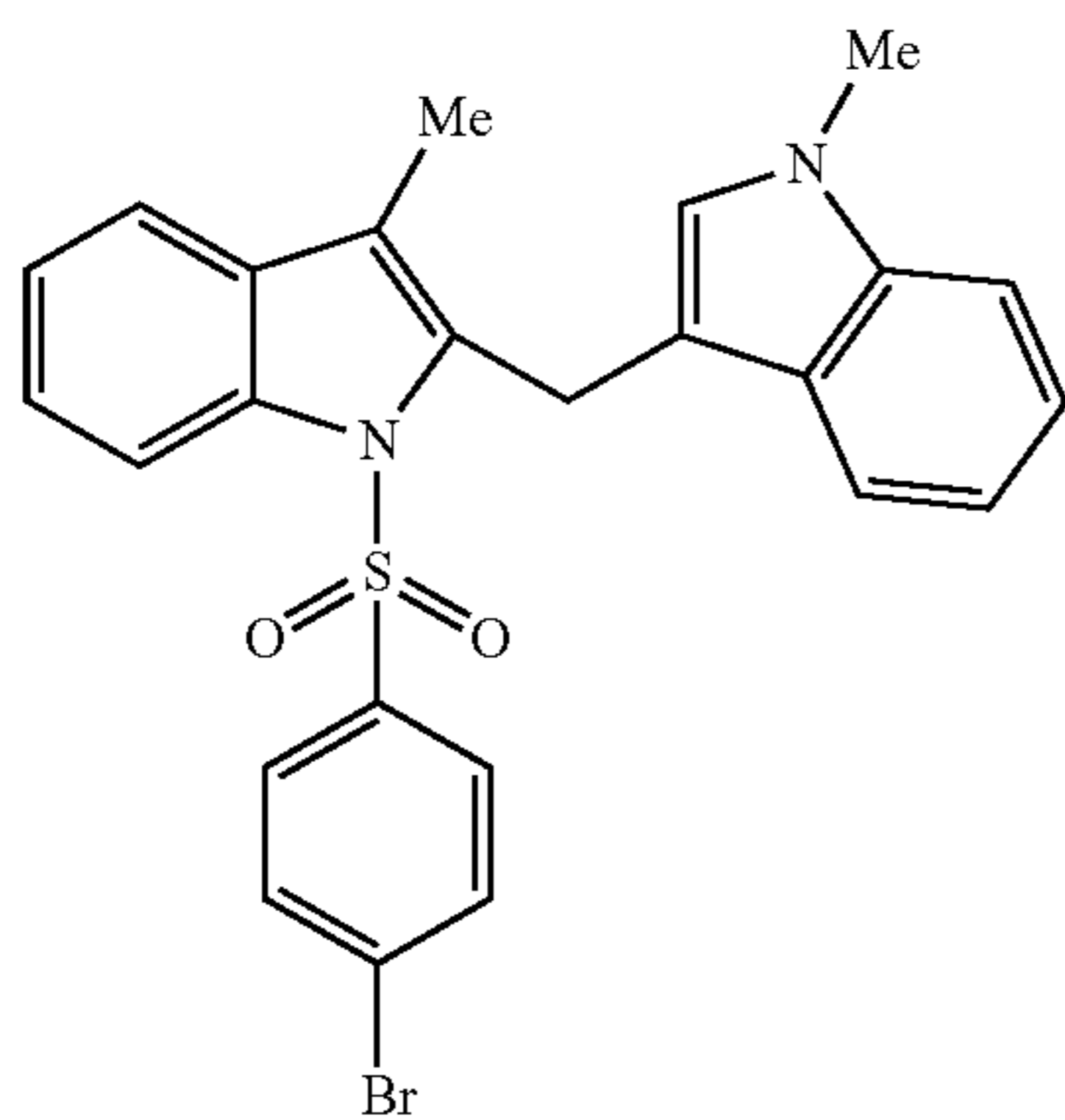
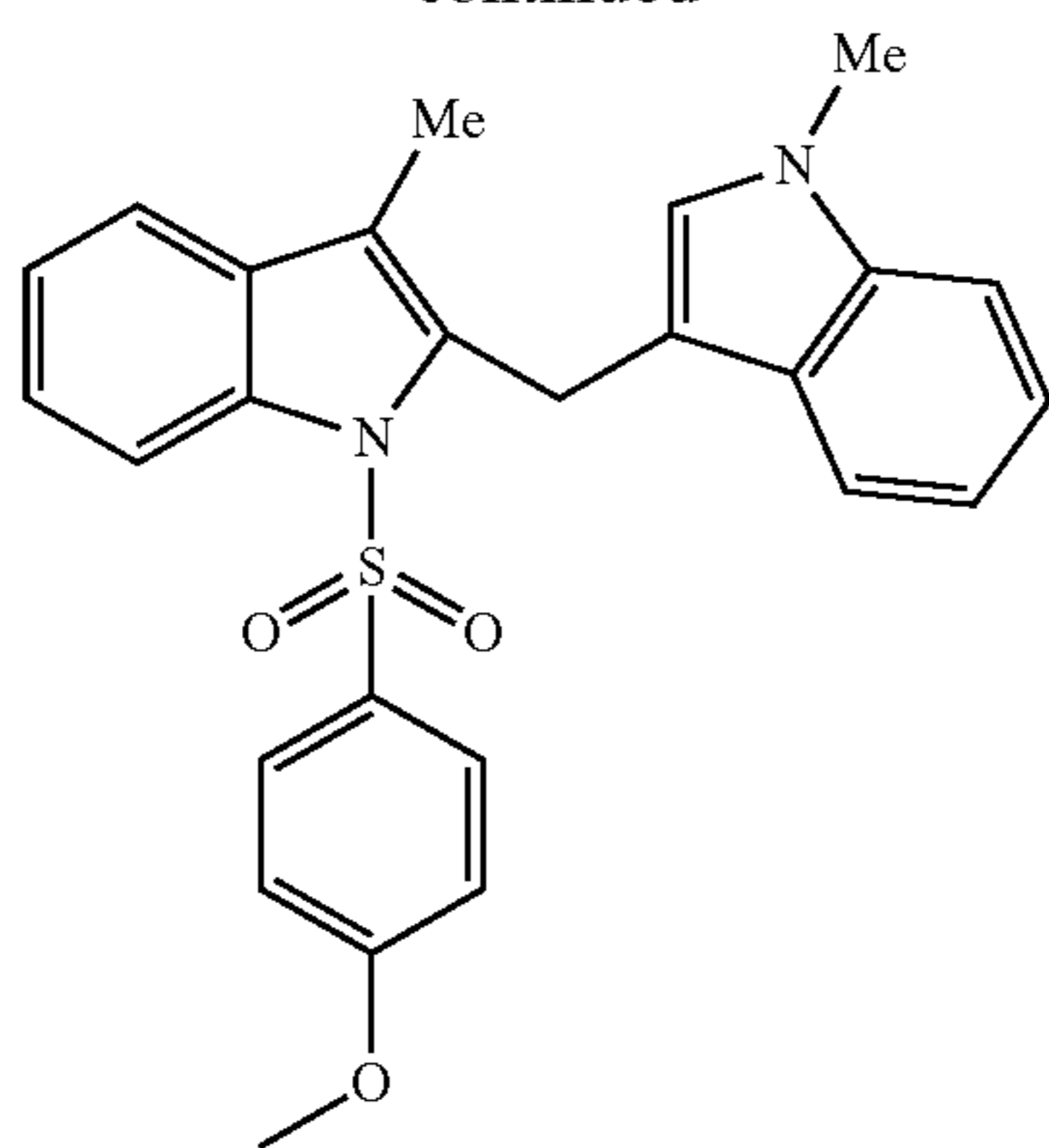
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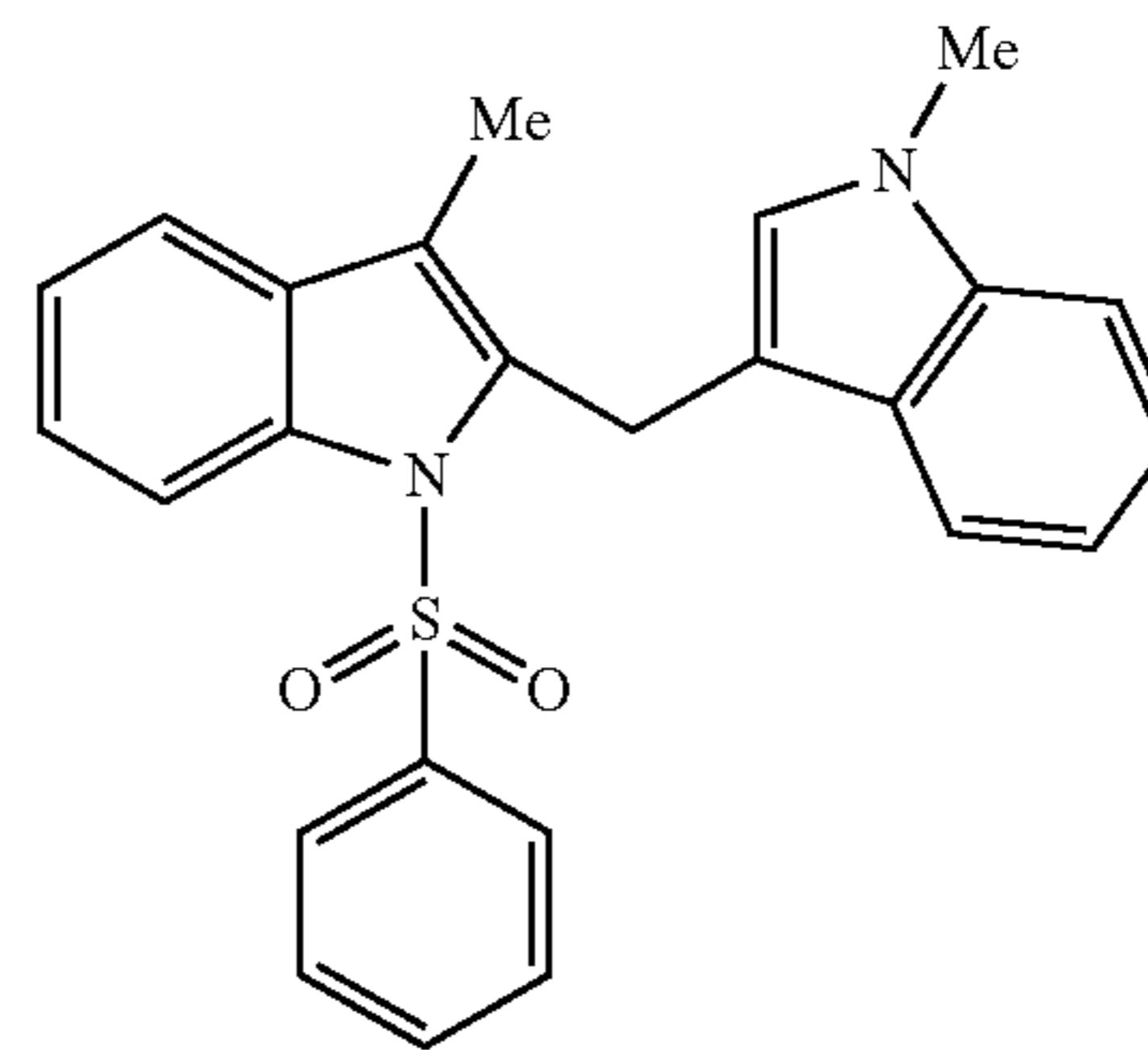
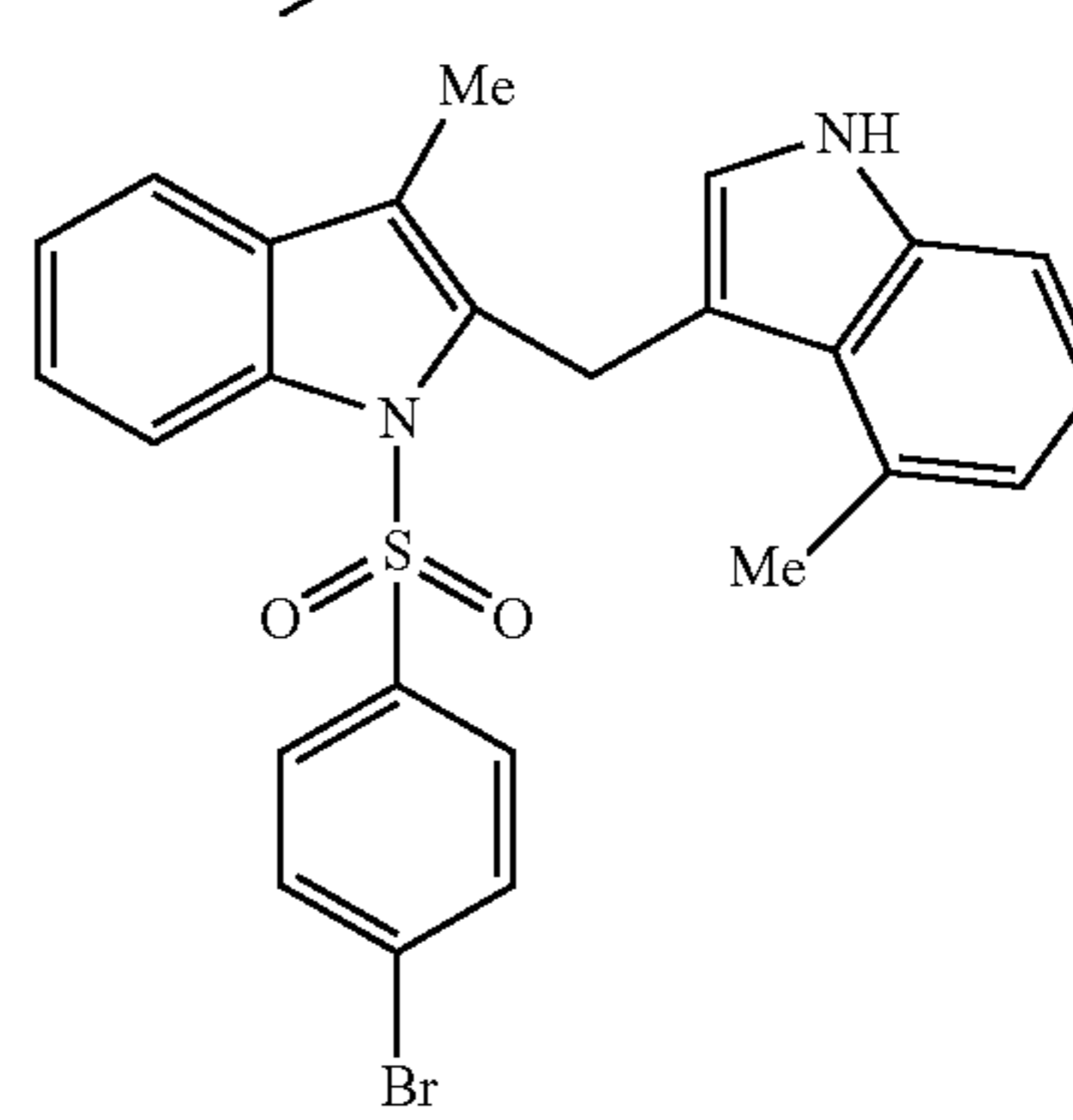
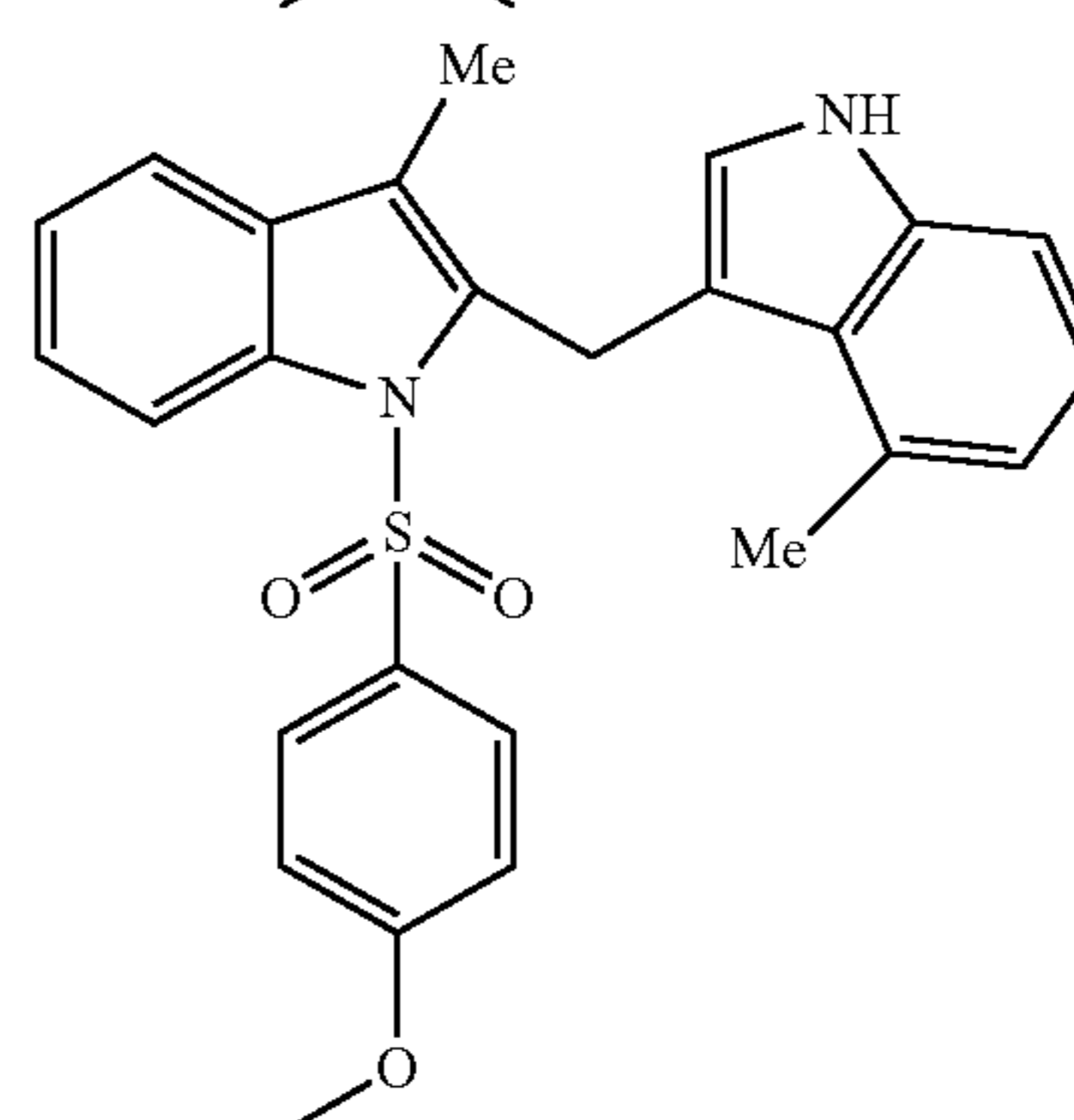
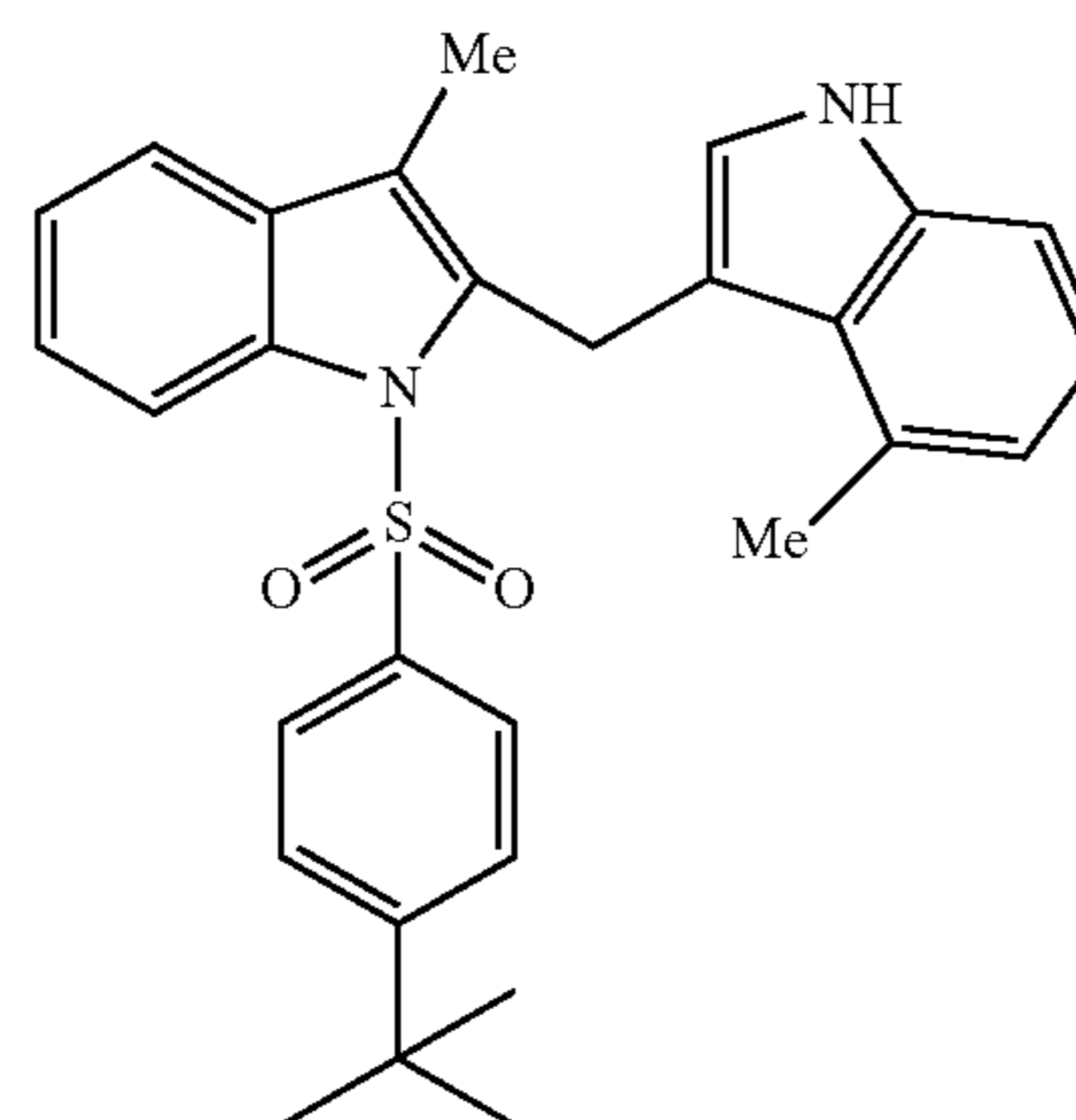
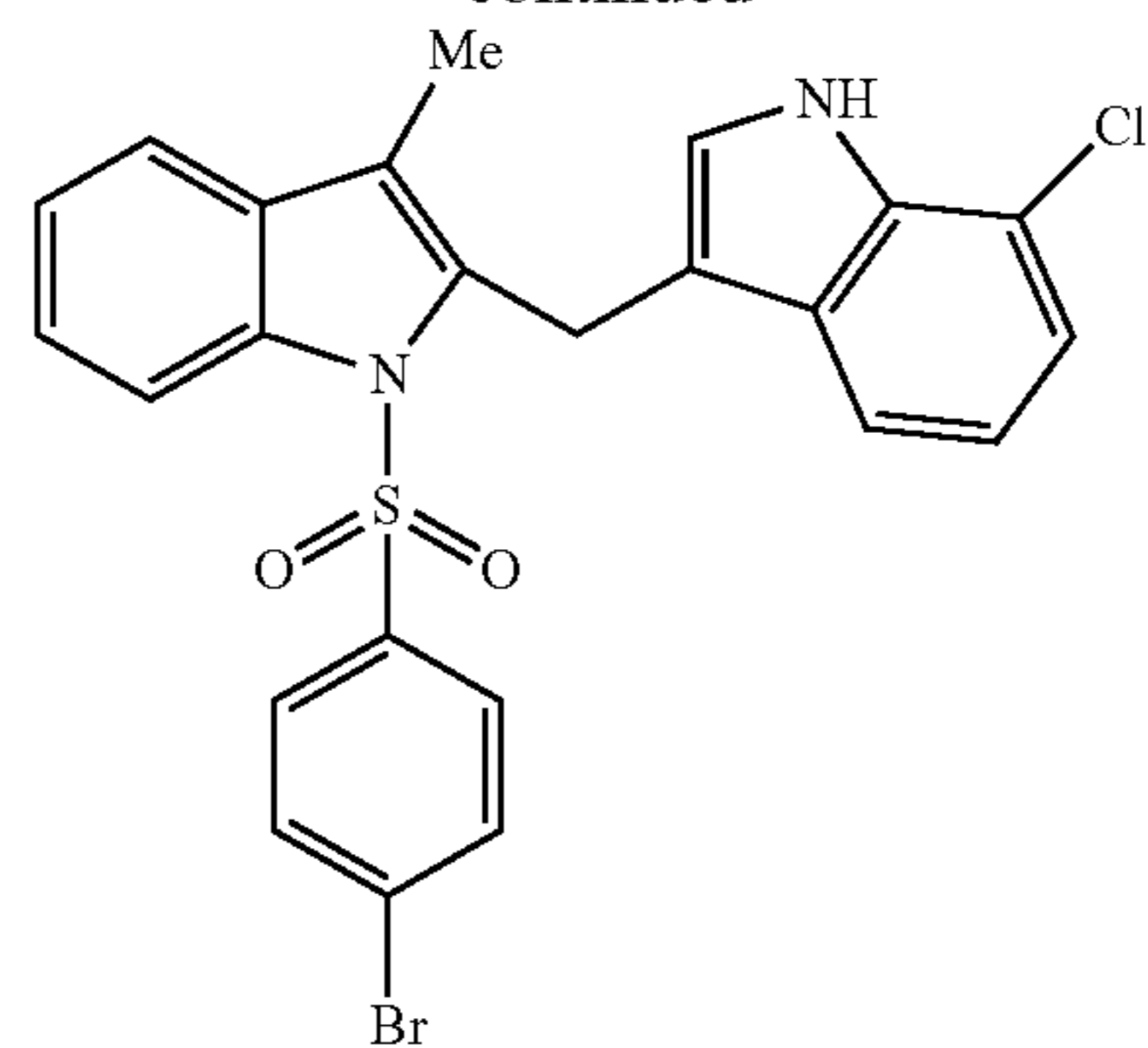
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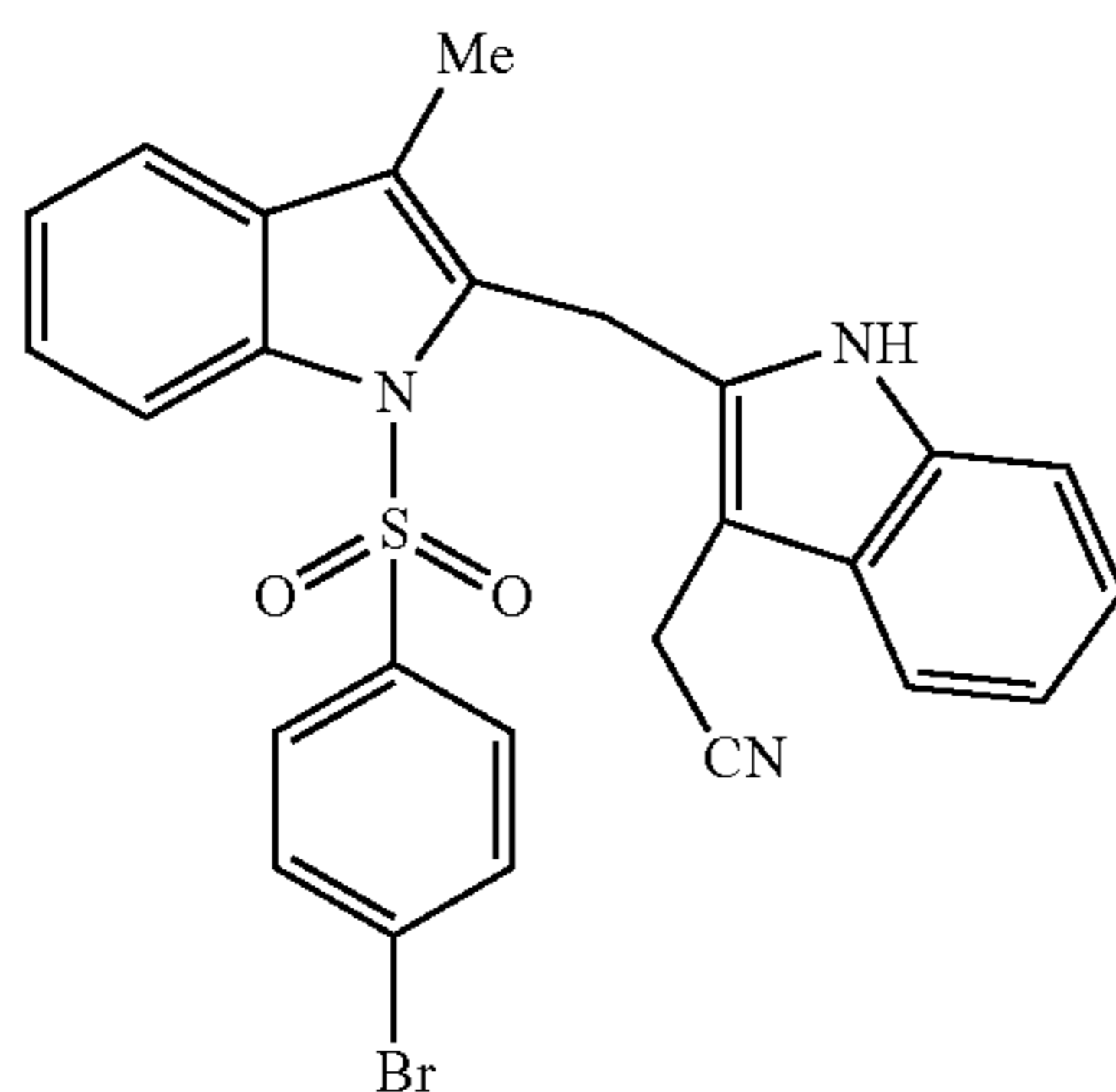
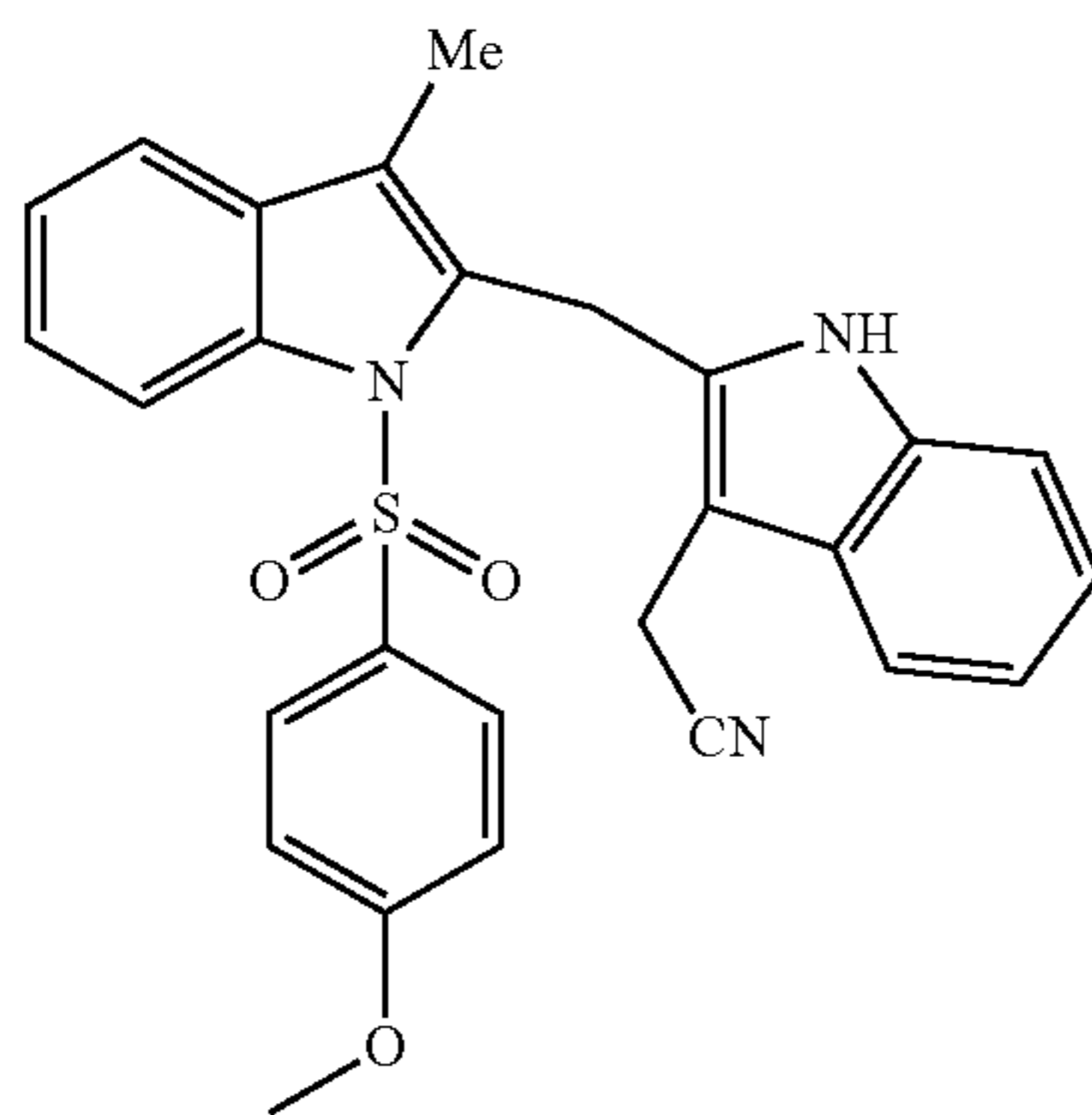
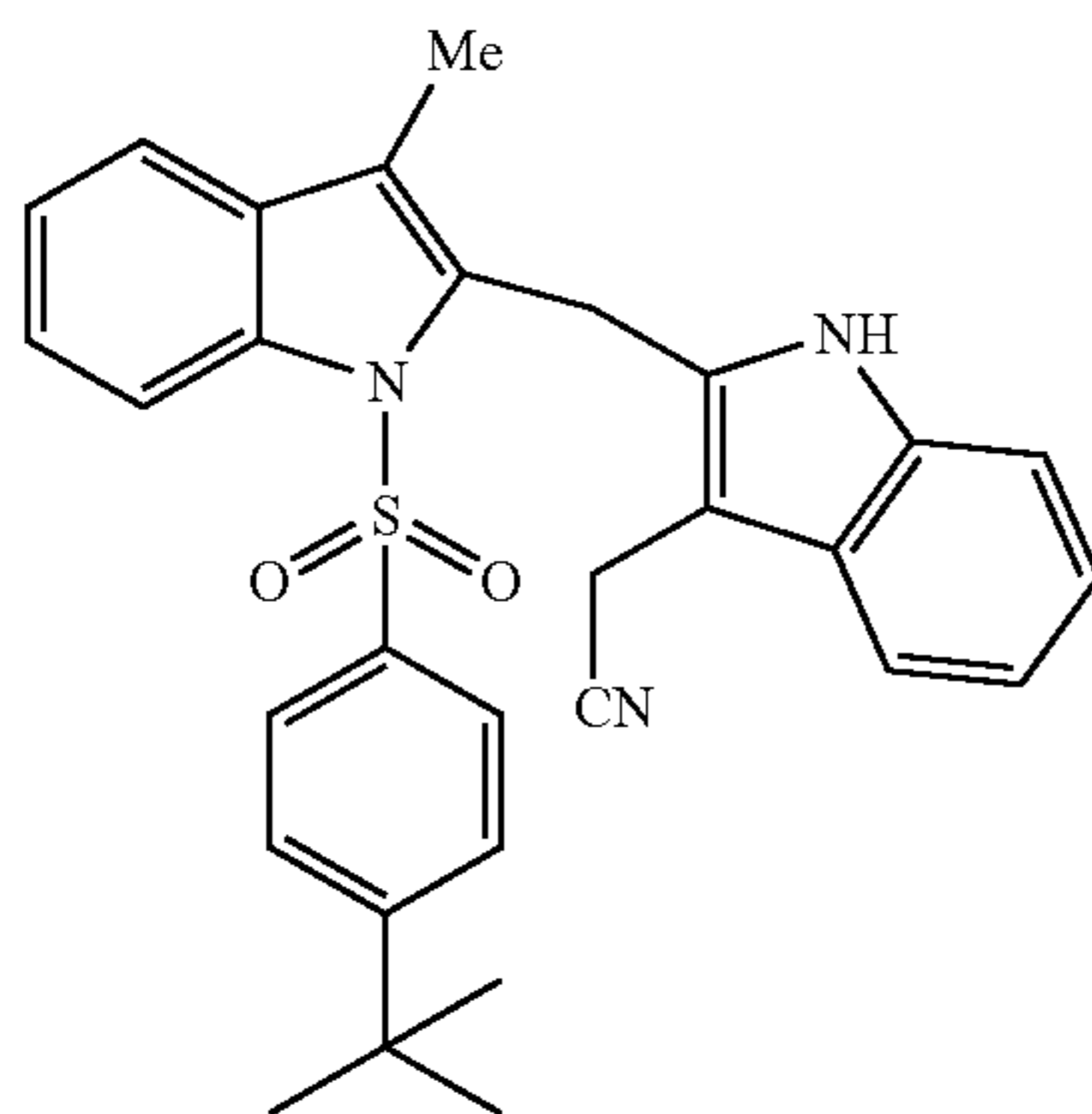
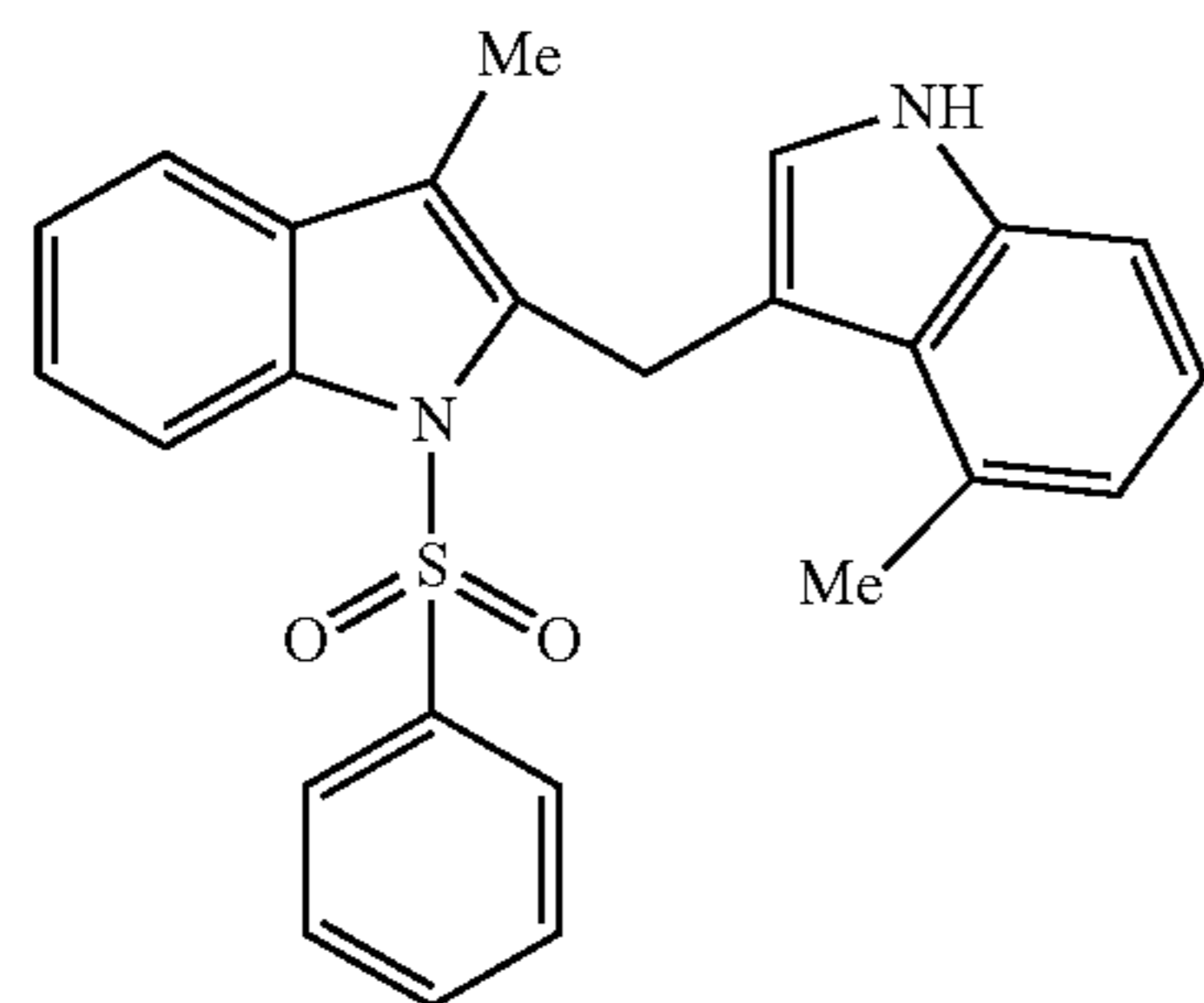
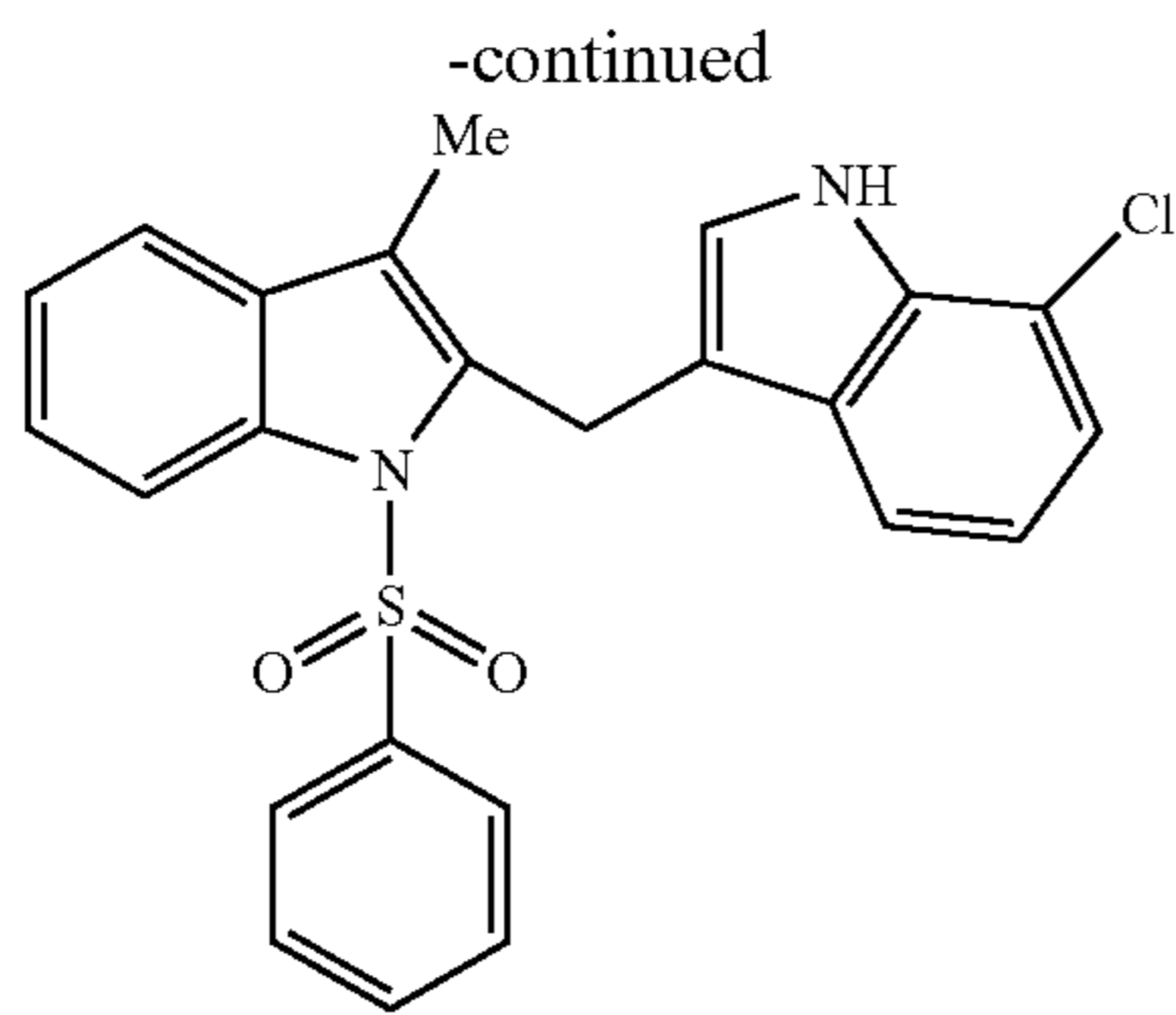


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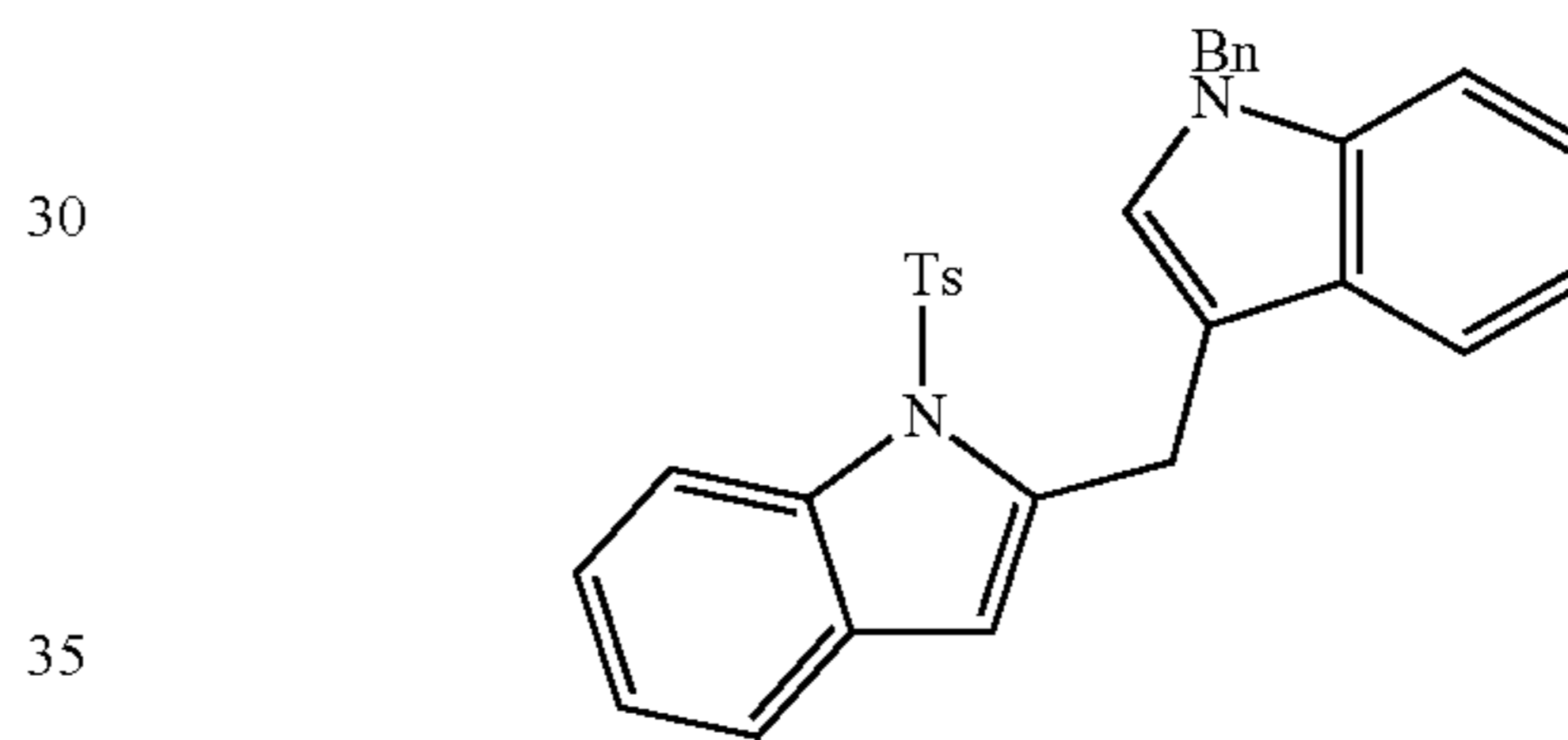
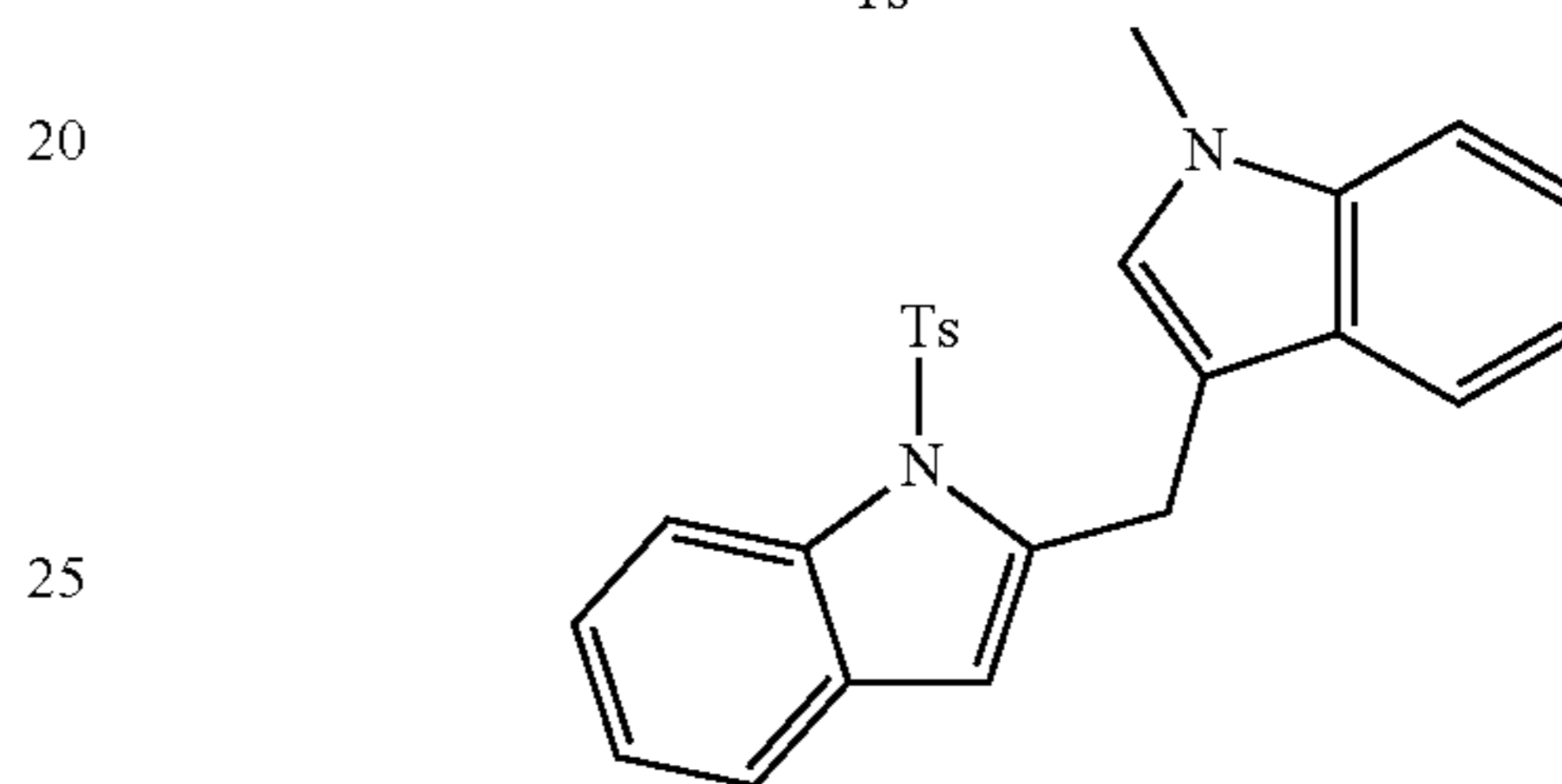
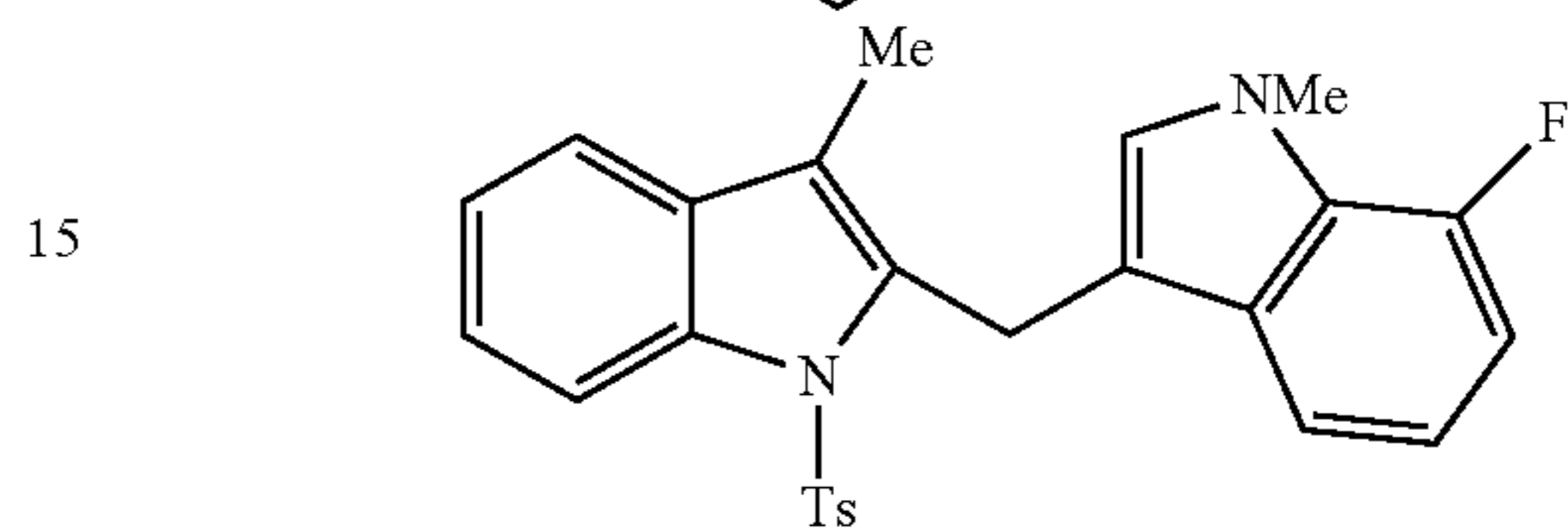
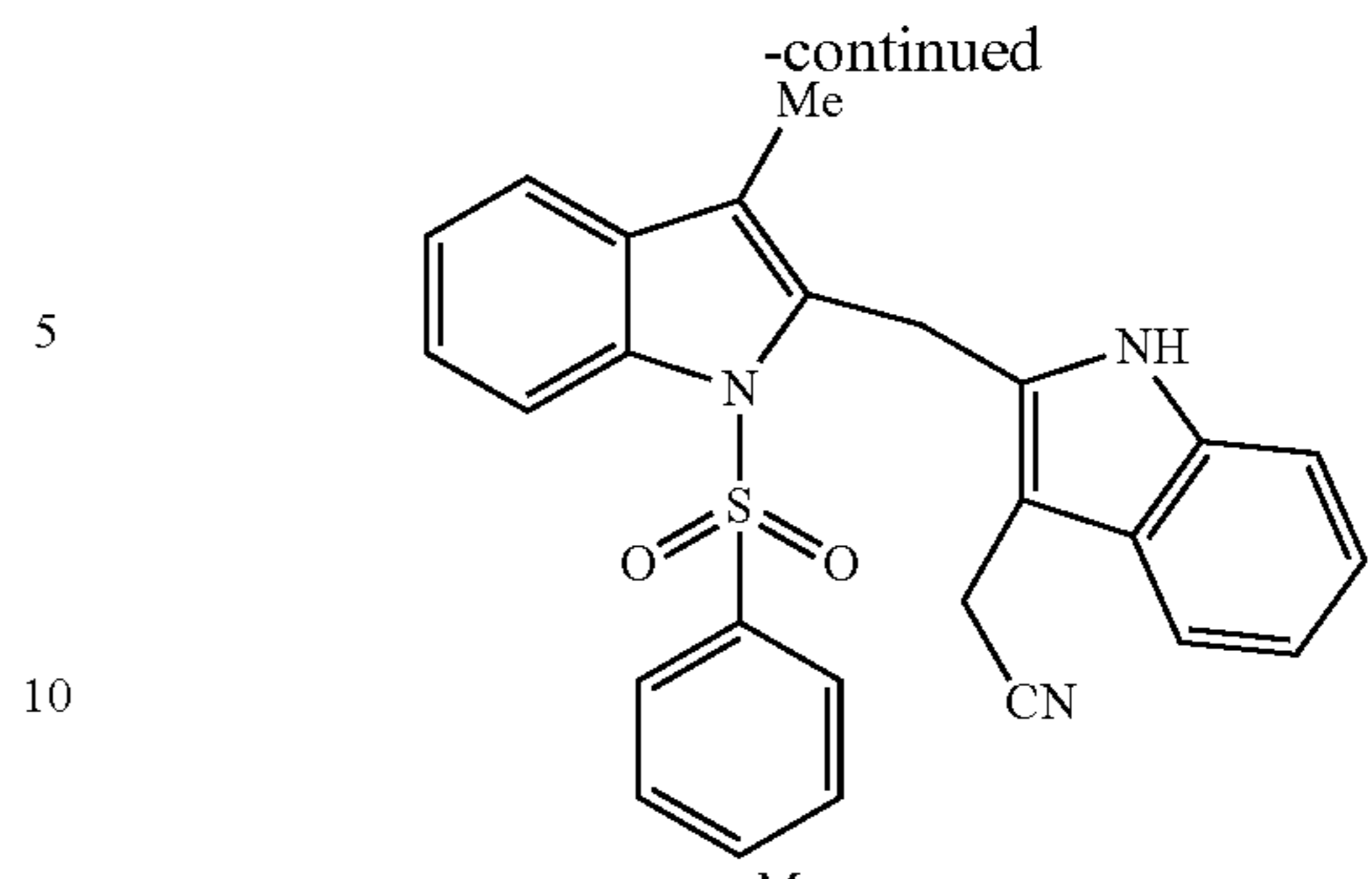
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## DETAILED DESCRIPTION

## Definitions

Numerical ranges as used herein are intended to include every number and subset of numbers contained within that range, whether specifically disclosed or not. Further, these numerical ranges should be construed as providing support for a claim directed to any number or subset of numbers in that range. For example, a disclosure of from 1 to 10 should be construed as supporting a range of from 2 to 8, from 3 to 7, from 1 to 9, from 3.6 to 4.6, from 3.5 to 9.9, and so forth.

All references to singular characteristics or limitations of the present invention shall include the corresponding plural characteristic or limitation, and vice-versa, unless otherwise specified or clearly implied to the contrary by the context in which the reference is made. That is, unless specifically stated to the contrary, "a" and "an" mean "one or more." The phrase "one or more" is readily understood by one of skill in the art, particularly when read in context of its usage. For example, "one or more" substituents on a phenyl ring designates one to five substituents.

All combinations of method or process steps as used herein can be performed in any order, unless otherwise specified or clearly implied to the contrary by the context in which the referenced combination is made.

The methods of the present invention can comprise, consist of, or consist essentially of the essential elements and limitations of the method described herein, as well as any

additional or optional ingredients, components, or limitations described herein or otherwise useful in synthetic organic chemistry.

The term “contacting” refers to the act of touching, making contact, or of bringing to immediate or close proximity, including at the molecular level, for example, to bring about a chemical reaction, or a physical change, e.g., in a solution or in a reaction mixture.

An “effective amount” refers to an amount of a chemical or reagent effective to facilitate a chemical reaction between two or more reaction components, and/or to bring about a recited effect. Thus, an “effective amount” generally means an amount that provides the desired effect.

The term “solvent” refers to any liquid that can dissolve a compound to form a solution. Solvents include water and various organic solvents, such as hydrocarbon solvents, for example, alkanes and aryl solvents, as well as halo-alkane solvents. Examples include hexanes, benzene, toluene, xylenes, chloroform, methylene chloride, dichloroethane, and alcoholic solvents such as methanol, ethanol, propanol, isopropanol, and linear or branched (sec or tert) butanol, and the like. Aprotic solvents that can be used in the method include, but are not limited to perfluorohexane,  $\alpha,\alpha,\alpha$ -trifluorotoluene, pentane, hexane, cyclohexane, methylcyclohexane, decalin, dioxane, carbon tetrachloride, freon-11, benzene, toluene, triethyl amine, carbon disulfide, diisopropyl ether, diethyl ether, t-butyl methyl ether (MTBE), chloroform, ethyl acetate, 1,2-dimethoxyethane (glyme), 2-methoxyethyl ether (diglyme), tetrahydrofuran (THF), methylene chloride, pyridine, 2-butanone (MEK), acetone, hexamethylphosphoramide, N-methylpyrrolidinone (NMP), nitromethane, dimethylformamide (DMF), acetonitrile, sulfolane, dimethyl sulfoxide (DMSO), propylene carbonate, and the like.

The term “alkyl” refers to a branched or unbranched carbon chain having, for example, about 1-20 carbon atoms, and often 1-12, 1-10, 1-8, 1-6, or 1-4 carbons. Examples include, but are not limited to, methyl, ethyl, 1-propyl, 2-propyl, 1-butyl, 2-methyl-1-propyl, 2-butyl, 2-methyl-2-propyl (t-butyl), 1-pentyl, 2-pentyl, 3-pentyl, 2-methyl-2-butyl, 3-methyl-2-butyl, 3-methyl-1-butyl, 2-methyl-1-butyl, 1-hexyl, 2-hexyl, 3-hexyl, 2-methyl-2-pentyl, 3-methyl-2-pentyl, 4-methyl-2-pentyl, 3-methyl-3-pentyl, 2-methyl-3-pentyl, 2,3-dimethyl-2-butyl, 3,3-dimethyl-2-butyl, hexyl, octyl, decyl, dodecyl, and the like. The alkyl can be unsubstituted or substituted. The alkyl can also be optionally partially or fully unsaturated in certain embodiments. As such, the recitation of an alkyl group optionally includes both alkenyl and alkynyl groups. The alkyl can be a monovalent hydrocarbon radical, as described and exemplified above, or it can be a divalent hydrocarbon radical (i.e., an alkylene). In some embodiments, certain alkyl groups can be excluded from a definition. For example, in some embodiments, methyl, ethyl, propyl, butyl, or a combination thereof, can be excluded from a specific definition of alkyl in an embodiment.

The term “cycloalkyl” refers to cyclic alkyl groups of, for example, 3 to about 12, 3 to about 10, 3 to about 8, about 4 to about 8, or 5-6, carbon atoms having a single cyclic ring or multiple condensed rings. Cycloalkyl groups include, by way of example, single ring structures such as cyclopropyl, cyclobutyl, cyclopentyl, cyclooctyl, and the like, or multiple ring structures such as adamantyl, and the like. The cycloalkyl can be unsubstituted or substituted. The cycloalkyl group can be monovalent or divalent, and can be optionally substituted as described for alkyl groups. The cycloalkyl group can optionally include one or more sites of

unsaturation, for example, the cycloalkyl group can include one or more carbon-carbon double bonds, such as, for example, 1-cyclopent-1-enyl, 1-cyclopent-2-enyl, 1-cyclopent-3-enyl, cyclohexyl, 1-cyclohex-1-enyl, 1-cyclohex-2-enyl, 1-cyclohex-3-enyl, and the like.

As used herein, “aryl” refers to an aromatic hydrocarbon group derived from the removal of one hydrogen atom from a single carbon atom of a parent aromatic ring system. The radical attachment site can be at a saturated or unsaturated carbon atom of the parent ring system. The aryl group can have from 6 to about 20 carbon atoms. The aryl group can have a single ring (e.g., phenyl) or multiple condensed (fused) rings, wherein at least one ring is aromatic (e.g., naphthyl, dihydrophenanthrenyl, fluorenyl, or anthryl). Typical aryl groups include, but are not limited to, radicals derived from benzene, naphthalene, anthracene, biphenyl, and the like. The aryl can be unsubstituted or optionally substituted, as described for alkyl groups.

The term “heteroaryl” refers to a monocyclic, bicyclic, or tricyclic ring system containing one, two, or three aromatic rings and containing at least one nitrogen, oxygen, or sulfur atom in an aromatic ring, and that can be unsubstituted or substituted, for example, with one or more, and in particular one to three, substituents, as described in the definition of “substituted”. Typical heteroaryl groups contain 2-20 carbon atoms in addition to the one or more heteroatoms. Examples of heteroaryl groups include, but are not limited to, 2H-pyrrolyl, 3H-indolyl, 4H-quinoliziny, acridinyl, benzo[b]thienyl, benzothiazolyl,  $\beta$ -carboline, carbazolyl, chromenyl, cinnolinyl, dibenzo[b,d]furanyl, furazanyl, furyl, imidazolyl, imidazolyl, indazolyl, indolisyl, indolyl, isobenzofuranyl, isoindolyl, isoquinolyl, isothiazolyl, isoxazolyl, naphthyridinyl, oxazolyl, perimidinyl, phenanthridinyl, phenanthrolinyl, phenarsazinyl, phenazinyl, phenothiazinyl, phenoxathiinyl, phenoxazinyl, phthalazinyl, pteridinyl, purinyl, pyranyl, pyrazinyl, pyrazolyl, pyridazinyl, pyridyl, pyrimidinyl, pyrimidinyl, pyrrolyl, quinazoliny, quinolyl, quinoxaliny, thiadiazolyl, thianthrenyl, thiazolyl, thienyl, triazolyl, tetrazolyl, and xanthenyl. In one embodiment the term “heteroaryl” denotes a monocyclic aromatic ring containing five or six ring atoms containing carbon and 1, 2, 3, or 4 heteroatoms independently selected from non-peroxide oxygen, sulfur, and N(Z) wherein Z is absent or is H, O, alkyl, aryl, or  $-(C1-C6)$ alkylaryl. In some embodiments, heteroaryl denotes an ortho-fused bicyclic heterocycle of about eight to ten ring atoms derived therefrom, particularly a benz-derivative or one derived by fusing a propylene, trimethylene, or tetramethylene diradical thereto.

The term “heterocycle” refers to a saturated or partially unsaturated ring system, containing at least one heteroatom selected from the group oxygen, nitrogen, silicon, and sulfur, and optionally substituted with one or more groups as defined for the term “substituted”. A heterocycle can be a monocyclic, bicyclic, or tricyclic group. A heterocycle group also can contain an oxo group ( $=O$ ) or a thioxo ( $=S$ ) group attached to the ring. Non-limiting examples of heterocycle groups include 1,3-dihydrobenzofuran, 1,3-dioxolane, 1,4-dioxane, 1,4-dithiane, 2H-pyran, 2-pyrazoline, 4H-pyran, chromanyl, imidazolidinyl, imidazoliny, indolinyl, isochromanly, isoindolinyl, morpholinyl, piperazinyl, piperidinyl, pyrazolidinyl, pyrazolinyl, pyrrolidine, pyrroline, quinuclidine, tetrahydrofuranyl, and thiomorpholine, where the point of attachment can be at any atom accessible by known synthetic methods.

The term “substituted” indicates that one or more hydrogen atoms on the group indicated in the expression using “substituted” is replaced with a “substituent”. The number

referred to by 'one or more' can be apparent from the moiety one which the substituents reside. For example, one or more can refer to, e.g., 1, 2, 3, 4, 5, or 6; in some embodiments 1, 2, or 3; and in other embodiments 1 or 2. The substituent can be one of a selection of indicated groups, or it can be a suitable group known to those of skill in the art, provided that the substituted atom's normal valency is not exceeded, and that the substitution results in a stable compound. Suitable substituent groups include, e.g., alkyl, alkenyl, alkynyl, alkoxy, halo, haloalkyl, hydroxy, hydroxyalkyl, aryl, aroyl, (aryl)alkyl (e.g., benzyl or phenylethyl), heteroaryl, heterocycle, cycloalkyl, alkanoyl, alkoxy-carbonyl, amino, alkylamino, dialkylamino, trifluoromethyl, trifluoromethoxy, trifluoromethylthio, difluoromethyl, acylamino, nitro, carboxy, carboxyalkyl, keto, thioxo, alkylthio, alkylsulfinyl, alkylsulfonyl, arylsulfinyl, arylsulfonyl, heteroaryl-sulfinyl, heteroarylsulfonyl, heterocyclesulfinyl, heterocyclesulfonyl, phosphate, sulfate, hydroxyl amine, hydroxyl (alkyl)amine, and cyano. Additionally, suitable substituent groups can be, e.g., —X, —R, —O—, —OR, —SR, —S—, —NR<sub>2</sub>, —NR<sub>3</sub>, =NR, —CX<sub>3</sub>, —CN, —OCN, —SCN, —N=C=O, —NCS, —NO, —NO<sub>2</sub>, =N<sub>2</sub>, —N<sub>3</sub>, —NC(=O)R, —C(=O)R, —C(=O)NRR, —S(=O)<sub>2</sub>O—, —S(=O)<sub>2</sub>OH, —S(=O)<sub>2</sub>R, —OS(=O)<sub>2</sub>OR, —S(=O)<sub>2</sub>NR, —S(=O)R, —OP(=O)O<sub>2</sub>RR, —P(=O)O<sub>2</sub>RR, —P(=O)(O—)<sub>2</sub>, —P(=O)(OH)<sub>2</sub>, —C(=O)R, —C(=O)X, —C(S)R, —C(O)OR, —C(O)O—, —C(S)OR, —C(O)SR, —C(S)SR, —C(O)NRR, —C(S)NRR, or —C(NR)NRR, where each X is independently a halogen ("halo"): F, Cl, Br, or I; and each R is independently H, alkyl, aryl, (aryl)alkyl (e.g., benzyl), heteroaryl, (heteroaryl)alkyl, heterocycle, heterocycle(alkyl), or a protecting group. As would be readily understood by one skilled in the art, when a substituent is keto (=O) or thioxo (=S), or the like, then two hydrogen atoms on the substituted atom are replaced. In some embodiments, one or more of the substituents above are excluded from the group of potential values for substituents on the substituted group.

A protecting group is any chemical moiety capable of selective addition to and removal from a reactive site to allow manipulation of a chemical entity at sites other than the reactive site. Many protecting groups are known in the art. A large number of protecting groups and corresponding chemical cleavage reactions are described in "Protective Groups in Organic Synthesis," Theodora W. Greene (John Wiley & Sons, Inc., New York, 1991, ISBN 0-471-62301-6) ("Greene", which is incorporated herein by reference). See also the 5<sup>th</sup> edition of this same work, published under the title "Greene's Protective Groups in Organic Synthesis," ISBN-13: 978-1118057483, ©2014, John Wiley & Sons, Inc. Greene describes many nitrogen protecting groups, for example, amide-forming groups. In particular, see Chapter 1, Protecting Groups: An Overview, Chapter 2, Hydroxyl Protecting Groups, Chapter 4, Carboxyl Protecting Groups, and Chapter 5, Carbonyl Protecting Groups. For additional information on protecting groups, see also Kocienski, Philip J. "Protecting Groups," (Georg Thieme Verlag Stuttgart, New York, 1994), which is incorporated herein by reference. Typical nitrogen protecting groups described in Greene include benzyl ethers, silyl ethers, esters including sulfonic acid esters, carbonates, sulfates, and sulfonates. For example, suitable nitrogen protecting groups include substituted methyl ethers; substituted ethyl ethers; p-chlorophenyl, p-methoxyphenyl, 2,4-dinitrophenyl, benzyl; substituted benzyl ethers (p-methoxybenzyl, 3,4-dimethoxybenzyl, o-nitrobenzyl, p-nitrobenzyl, p-halobenzyl, 2,6-dichlorobenzyl, p-cyanobenzyl, p-phenylbenzyl, 2- and 4-picoyl,

diphenylmethyl, 5-dibenzosuberyl, triphenylmethyl, p-methoxyphenyl-diphenylmethyl, di(p-methoxyphenyl)phenylmethyl, tri(p-methoxyphenyl)methyl, 1,3-benzodithiolan-2-yl, benzisothiazolyl S,S-dioxido); silyl ethers (silyloxy groups) (trimethylsilyl, triethylsilyl, triisopropylsilyl, dimethylisopropylsilyl, diethylisopropylsilyl, dimethylhexylsilyl, t-butyl-dimethylsilyl, t-butyl-diphenylsilyl, tribenzylsilyl, tri-p-xylylsilyl, triphenylsilyl, diphenylmethylsilyl, t-butylmethoxy-phenylsilyl); esters (formate, benzoylformate, acetate, chloroacetate, dichloroacetate, trichloroacetate, trifluoroacetate, methoxyacetate, triphenylmethoxyacetate, phenoxyacetate, p-chlorophenoxyacetate, 3-phenylpropionate, 4-oxopentanoate (levulinate), pivaloate, adamantoate, crotonate, 4-methoxycrotonate, benzoate, p-phenylbenzoate, 2,4,6-trimethylbenzoate(mesitoate)); carbonates (methyl, 9-fluorenylmethyl, ethyl, 2,2,2-trichloroethyl, 2-(trimethylsilyl)ethyl, 2-(phenylsulfonyl)ethyl, 2-(triphenylphosphonio)ethyl, isobutyl, vinyl, allyl, p-nitrophenyl, benzyl, p-methoxybenzyl, 3,4-dimethoxybenzyl, o-nitrobenzyl, p-nitrobenzyl, S-benzyl thiocarbonate, 4-ethoxy-1-naphthyl, methyl dithiocarbonate); groups with assisted cleavage (2-iodobenzoate, 4-azidobutyrate, 4-nitro-4-methylpentanoate, o-(dibromomethyl)benzoate, 2-formylbenzenesulfonate, 2-(methylthiomethoxy)ethyl carbonate, 4-(methylthiomethoxy)butyrate, miscellaneous esters (2,6-dichloro-4-methylphenoxyacetate, 2,6-dichloro-4-(1,1,3,3-tetramethylbutyl)phenoxyacetate, 2,4-bis(1,1-dimethylpropyl)phenoxyacetate, chlorodiphenylacetate, isobutyrate, monosuccinate, (E)-2-methyl-2-butenate (tigloate), o-(methoxycarbonyl)benzoate, p-poly-benzoate, α-naphthoate, nitrate, alkyl N,N,N',N'-tetramethyl-phosphorodiamidate, n-phenylcarbamate, borate, 2,4-dinitrophenyl-sulfenate); or sulfonates (methanesulfonate(mesylyte), benzenesulfonate, benzylsulfonate, tosylate, or triflate).

The more common of the amine-protecting groups have trivial abbreviations that are widely used in the literature and include: carbobenzyloxy (Cbz) group (removed by hydrogenolysis), p-methoxybenzyl carbonyl (Moz or MeOZ) group (removed by hydrogenolysis), tert-butyloxycarbonyl (BOC) group (common in solid phase peptide synthesis; removed by concentrated strong acid (such as HCl or CF<sub>3</sub>COOH), or by heating to >80° C., 9-fluorenylmethyloxycarbonyl (Fmoc) group (also common in solid phase peptide synthesis; removed by base, such as piperidine), acetyl (Ac) group (removed by treatment with a base), benzoyl (Bz) group (removed by treatment with a base), benzyl (Bn) group (removed by hydrogenolysis), carbamate group (removed by acid and mild heating), p-methoxybenzyl (PMB) (removed by hydrogenolysis), 3,4-dimethoxybenzyl (DMPM) (removed by hydrogenolysis), p-methoxyphenyl (PMP) group (removed by ammonium cerium(IV) nitrate (CAN)), tosyl (Ts) group (removed by concentrated acid and strong reducing agents), sulfonamide groups (Nosyl & Nps; removed by samarium iodide, tributyltin hydride).

A "pharmaceutically-suitable salt" is any acid or base addition salt whose counter-ions are non toxic to a patient (including a veterinary patient) in pharmaceutical doses of the salts, so that the beneficial pharmacological effects inherent in the free base or free acid are not vitiated by side effects ascribable to the counter-ions. A host of pharmaceutically-suitable salts are well known in the art. For basic active ingredients, all acid addition salts are useful as sources of the free base form even if the particular salt, per se, is desired only as an intermediate product as, for example, when the salt is formed only for purposes of purification, and identification, or when it is used as intermediate in preparing a pharmaceutically-suitable salt by ion

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exchange procedures. Pharmaceutically-suitable salts include, without limitation, those derived from mineral acids and organic acids, explicitly including hydrohalides, e.g., hydrochlorides and hydrobromides, sulphates, phosphates, nitrates, sulphamates, acetates, citrates, lactates, tartrates, malonates, oxalates, salicylates, propionates, succinates, fumarates, maleates, methylene bis-b-hydroxynaphthoates, gentisates, isethionates, di-p-toluoyltartrates, methane sulphates, ethanesulphonates, benzenesulphonates, p-toluenesulphonates, cyclohexylsulphamates, quinate, and the like. Base addition salts include those derived from alkali or alkaline earth metal bases or conventional organic bases, such as triethylamine, pyridine, piperidine, morpholine, N-methylmorpholine, and the like.

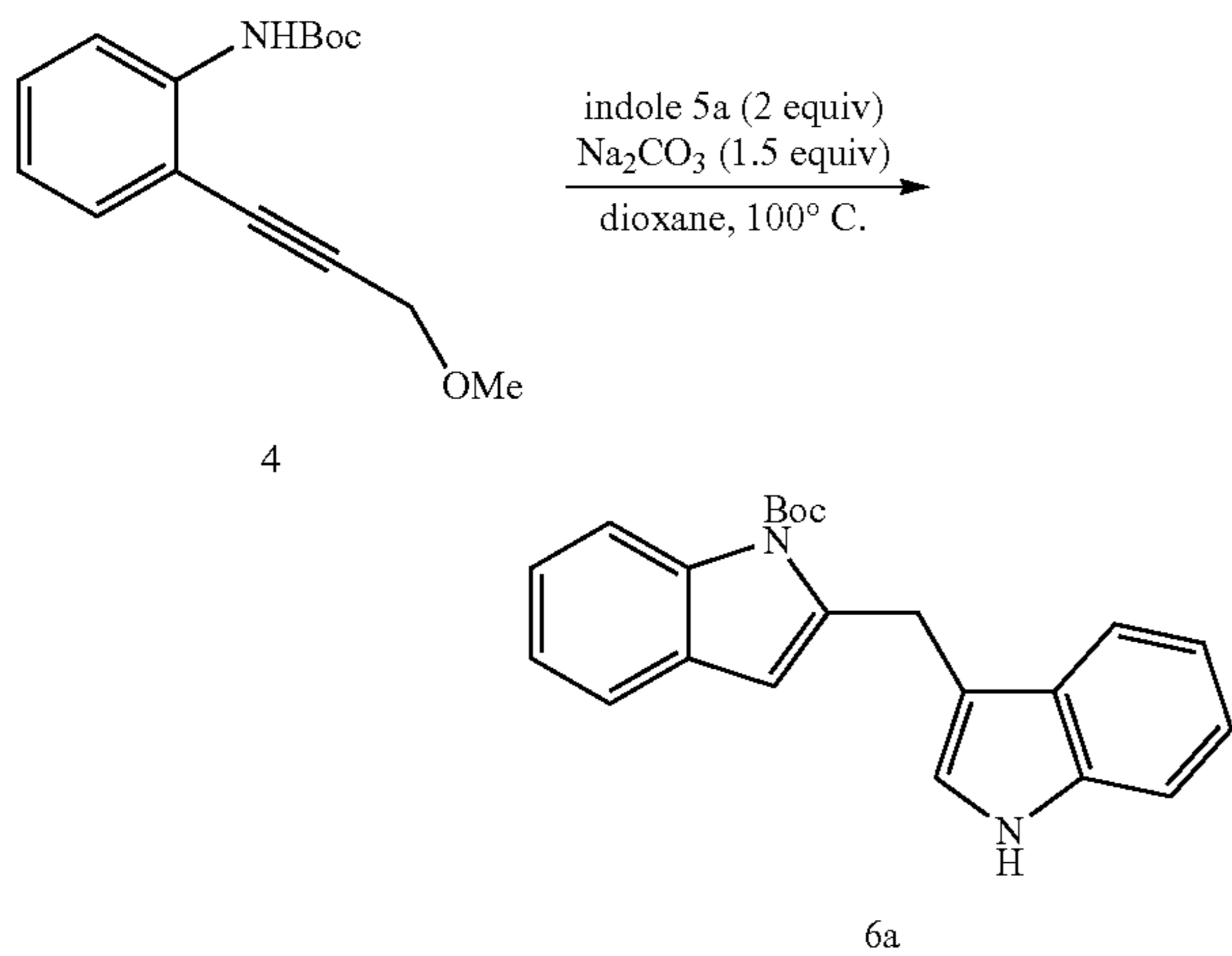
The Method:

The synthetic approach is most easily disclosed by way of an example. The example is for brevity and ease of explanation only. It does not limit the scope of the method disclosed and claimed herein in any fashion. Referring specifically to Table 1, a metal carbene intermediate was generated from annulation of propargylic ether 4 and trapped previously by a diene in a (4+3) cycloaddition. Shu, D.; Song, W.; Li, X.; Tang, W. *Angew. Chem. Int. Ed.*, 2013, 52, 3237. The present inventors envisioned that this metal carbene intermediate could also be trapped by other nucleophiles. Thus, it was thought that in the presence of another indole, diindolylmethanes could then be prepared conveniently.

As shown in Table 1, both Pt- and Rh-complexes promoted the formation of the 2,3'-diindolylmethane product 6a, though the former provided a higher yield. A slightly lower yield was obtained with lower catalyst loading (entry 3; 5 mol % catalyst vs. 10 mol %). In the case of indole annulation/arylation to form diindolylmethanes, using PtCl<sub>2</sub> alone as the catalyst appeared to be sufficient (entry 4). The yield again became slightly lower if the amount of catalyst was lowered to 5 mol % (entry 5). Other metal complexes did not produce any desired product (entries 6-10).

TABLE 1

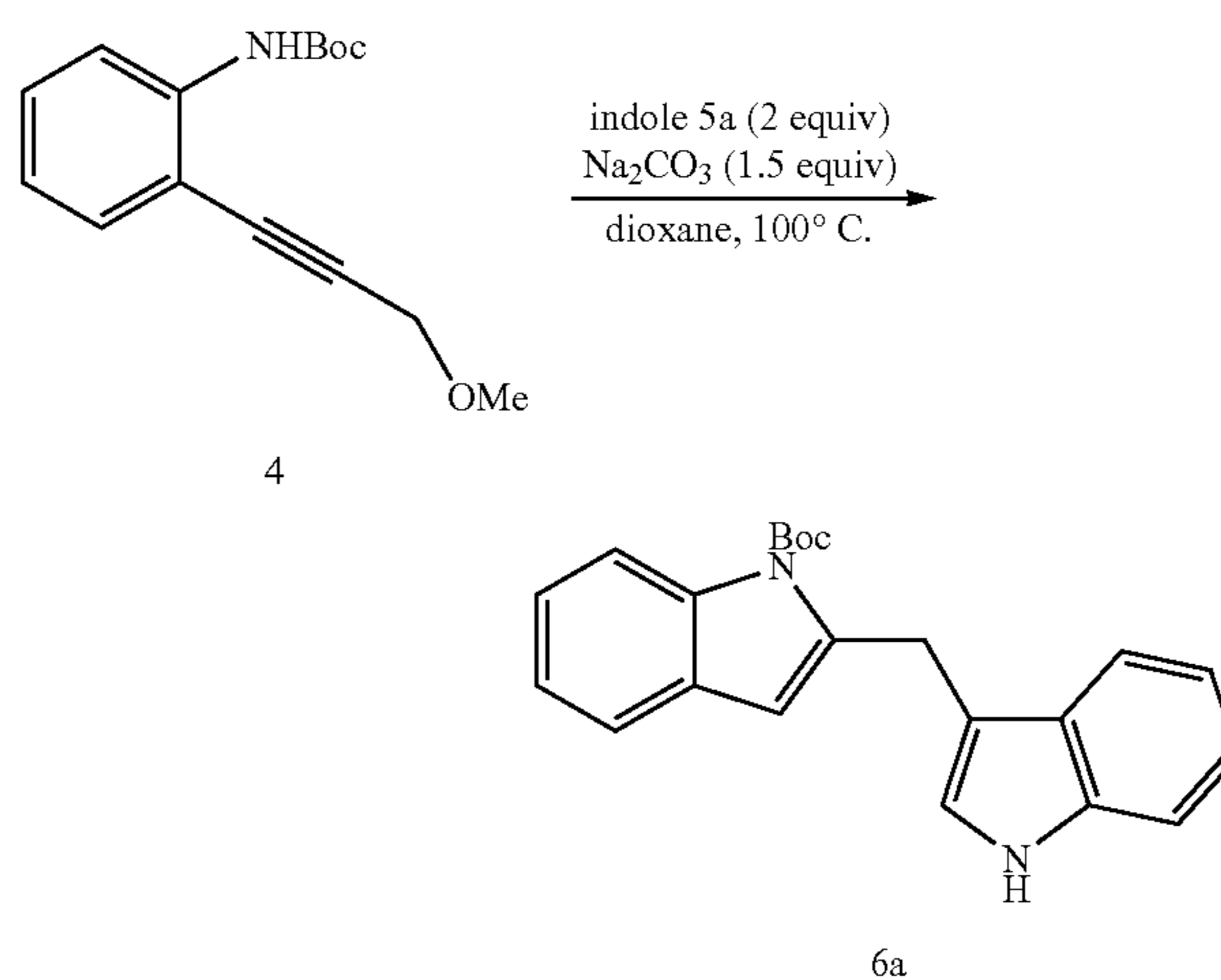
Screening of Catalysts and Conditions <sup>a</sup>		
entry	Conditions	yield (%)
1	PtCl <sub>2</sub> (10 mol %), P(C <sub>6</sub> F <sub>5</sub> ) <sub>3</sub> (20 mol %)	84
2	[Rh(CO) <sub>2</sub> Cl] <sub>2</sub> (10 mol %), P[OCH(CF <sub>3</sub> ) <sub>2</sub> ] <sub>3</sub> (20 mol %)	56
3	PtCl <sub>2</sub> (5 mol %), P(C <sub>6</sub> F <sub>5</sub> ) <sub>3</sub> (10 mol %)	77
4	PtCl <sub>2</sub> (10 mol %)	83 <sup>b</sup>



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TABLE 1-continued

Screening of Catalysts and Conditions <sup>a</sup>		
entry	Conditions	yield (%)
5	PtCl <sub>2</sub> (5 mol %)	76
6	AgBF <sub>4</sub> (10 mol %)	0
7	AgOTf (10 mol %)	0
8	CuOTf (10 mol %)	0
9	AgOTf (10 mol %), P(C <sub>6</sub> F <sub>5</sub> ) <sub>3</sub> (20 mol %)	0
10	CuOTf (10 mol %), P(C <sub>6</sub> F <sub>5</sub> ) <sub>3</sub> (20 mol %)	0



<sup>a</sup>Unless noted otherwise, the yield of 6a was determined by <sup>1</sup>H NMR of crude product.

<sup>b</sup>Isolated yield.

The scope of different indoles was examined for this tandem indole annulation/arylation cascade using propargylic ether 4 as the starting material (Table 2). N-Methyl indole 5b afforded a high yield of the 2,3'-diindolyl methane product 6b. The yield became 20% lower for 4-Br substituted N-methylindole 5c. Interestingly, the 4-cyano substituted indole 5d did not interfere with the efficiency of the tandem reaction. The indole annulation/arylation reaction could also tolerate electron-donating methoxy or halogen substituents on the 5- or 6-position of the indole (e.g. 5e, 5f, 5g, and 5h). The effect of substituent on the 2- and 3-position of indole 5 was then studied. With a 2-phenyl substituent on indole 5i, the yield of product 6i is comparable to 6a. When the intrinsically more reactive 3-position of the indole is blocked as in substrate 5j, a 2,2'-diindolylmethane was obtained in 60% yield.

Various substitutions on aniline and propargylic ether reactants was also investigated (Table 3). Substitutions at the para-position of the aniline were studied to examine how the change of pK<sub>a</sub> of the aniline influenced the efficiency of the reaction. It was found that anilines with either an electron-donating methoxy group or an electron-withdrawing ester group at the para-position participated most effectively in the tandem reaction. Aniline 7a with an electron-donating para methoxy group provided a higher yield of the desired product than the one with a para electron-withdrawing group (7b). A moderate 55% yield was observed when aniline 7c with a free hydroxyl group was employed as the substrate. Secondary propargylic ether 7d also participated in the tandem reaction and afforded diindolylethane 8d.

TABLE 2

Scope of Indoles for Pt-Catalyzed Tandem Indole Annulation/Arylation of Propargylic Ether 4<sup>a</sup>

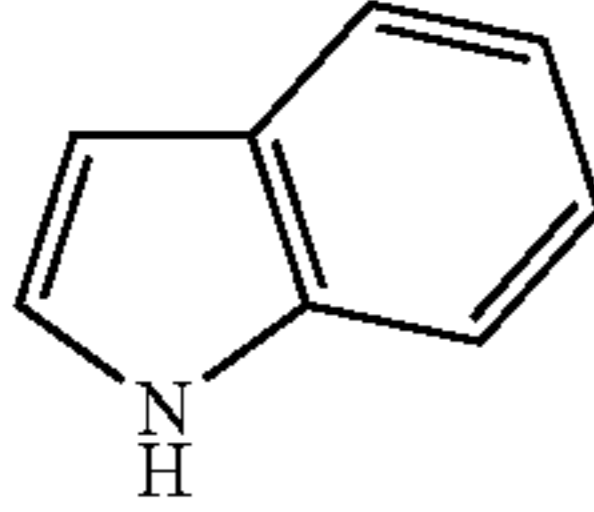
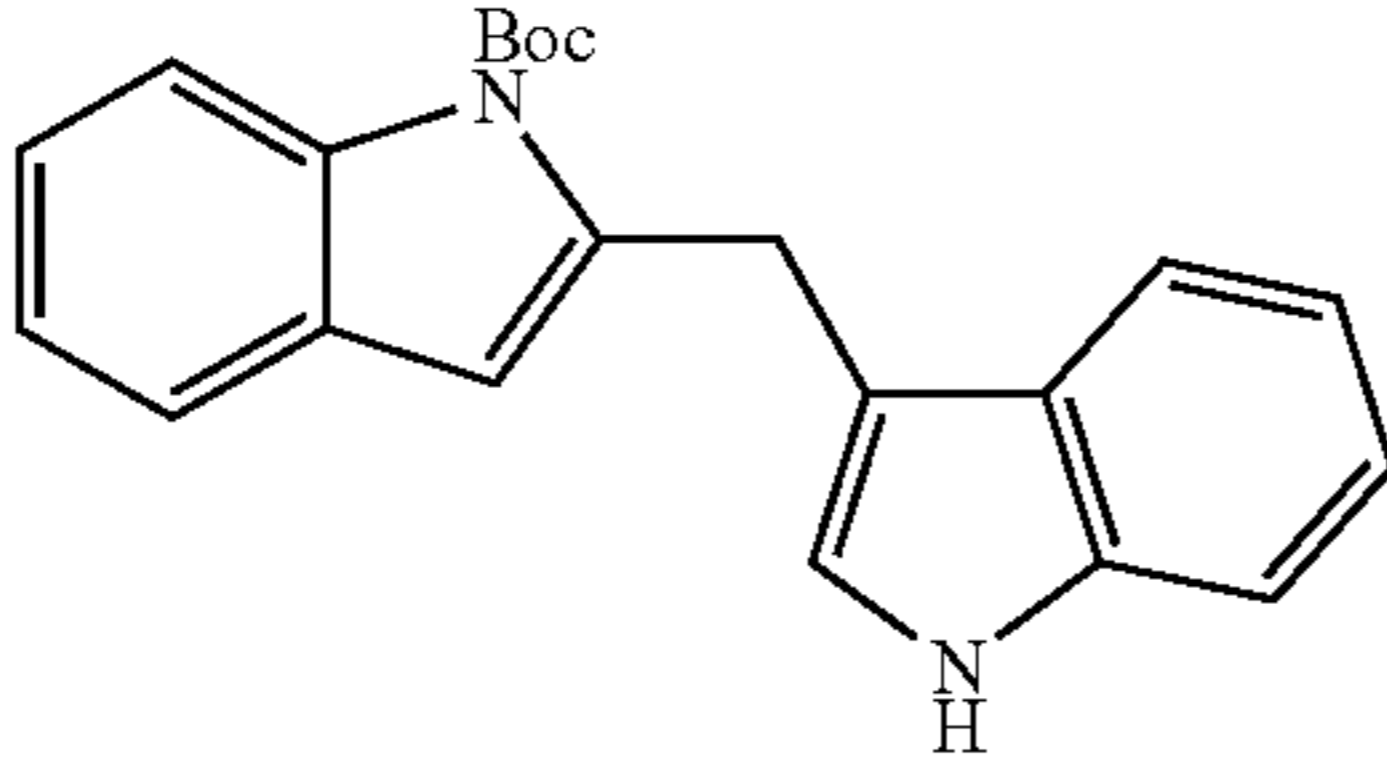
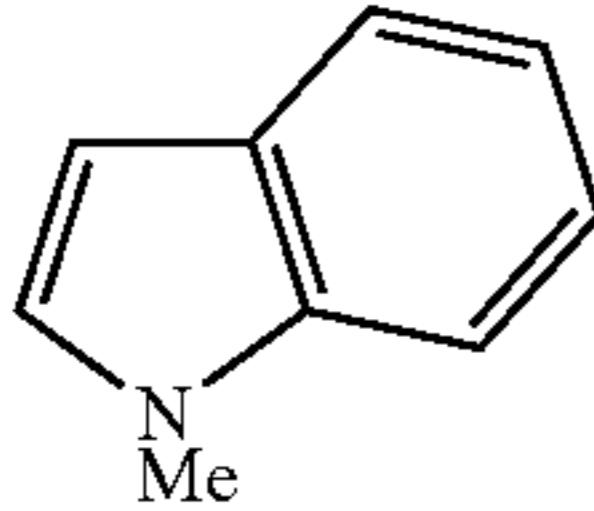
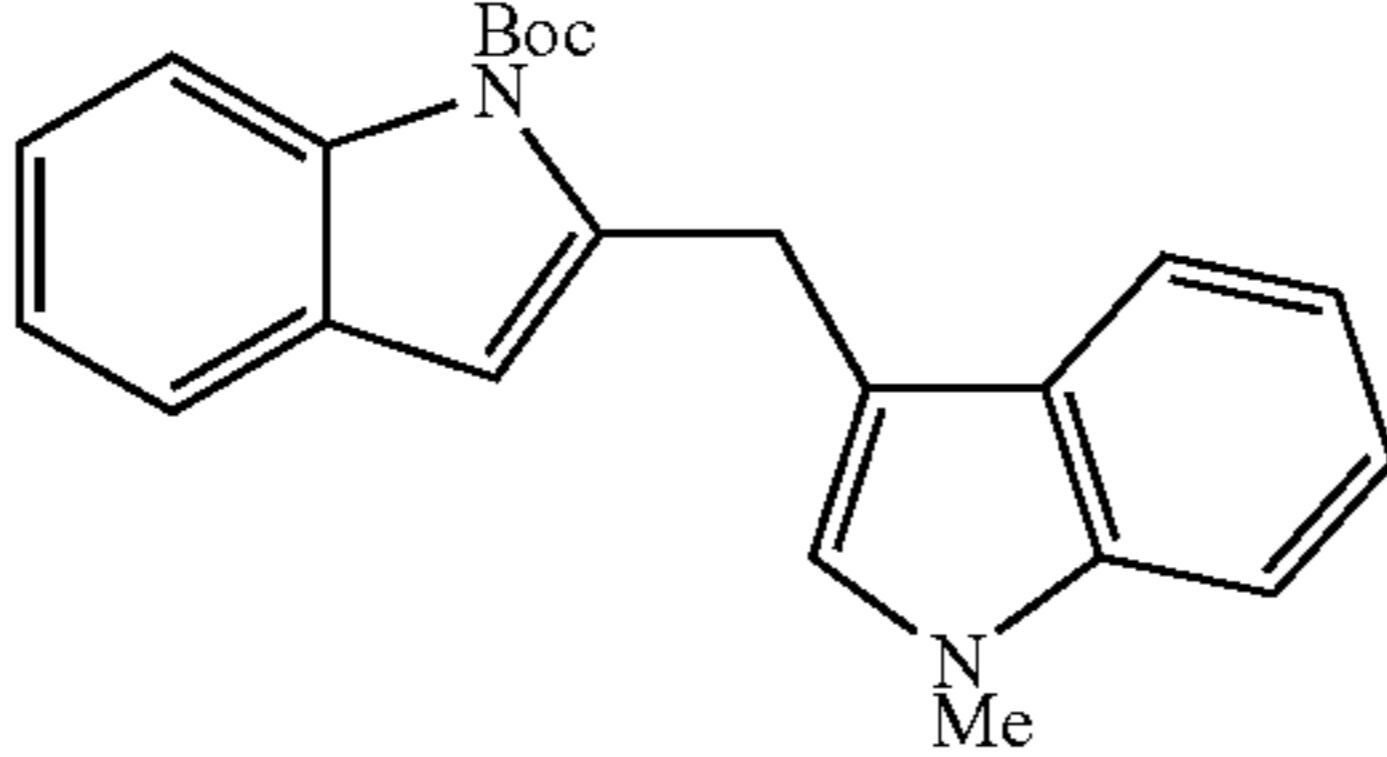
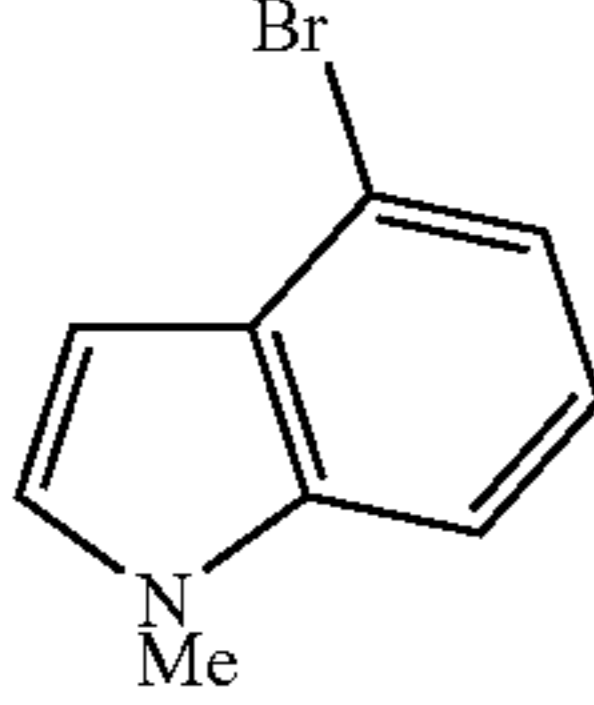
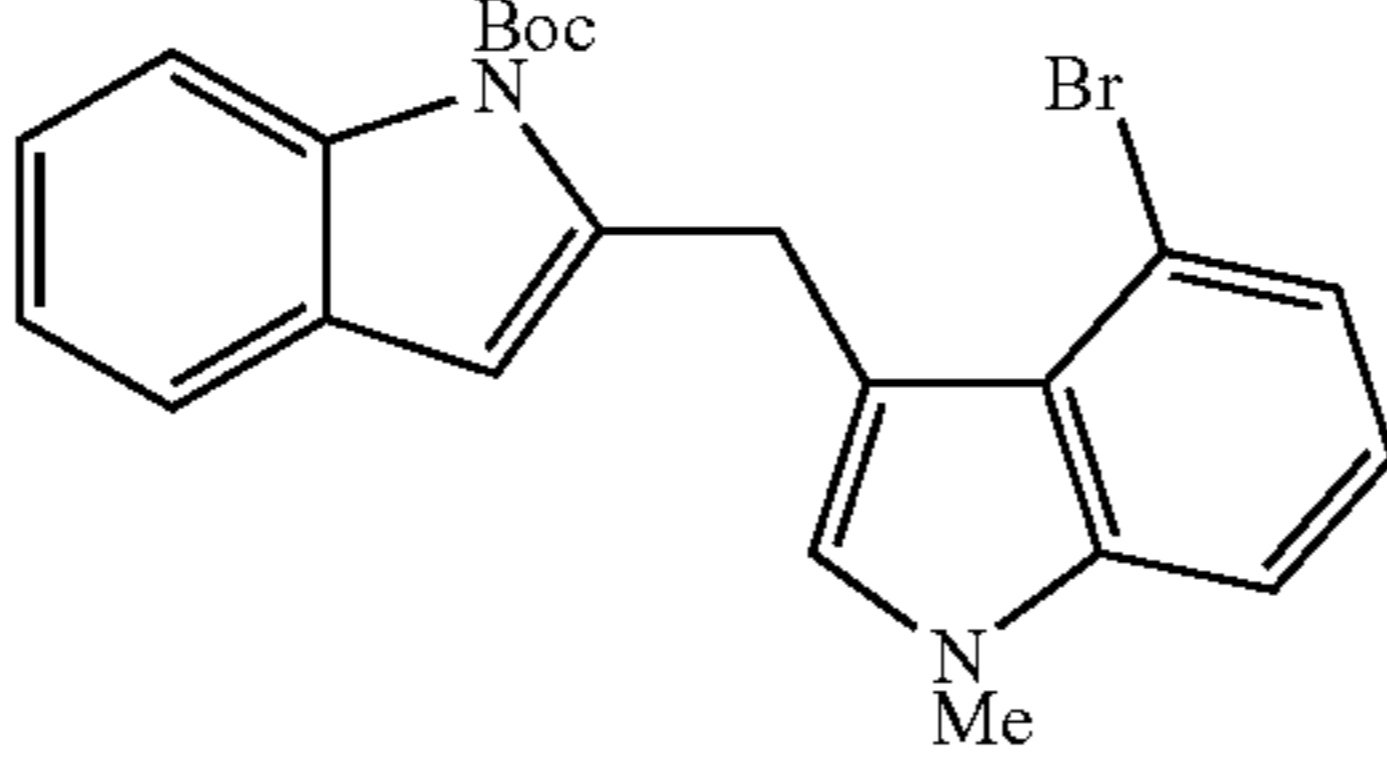
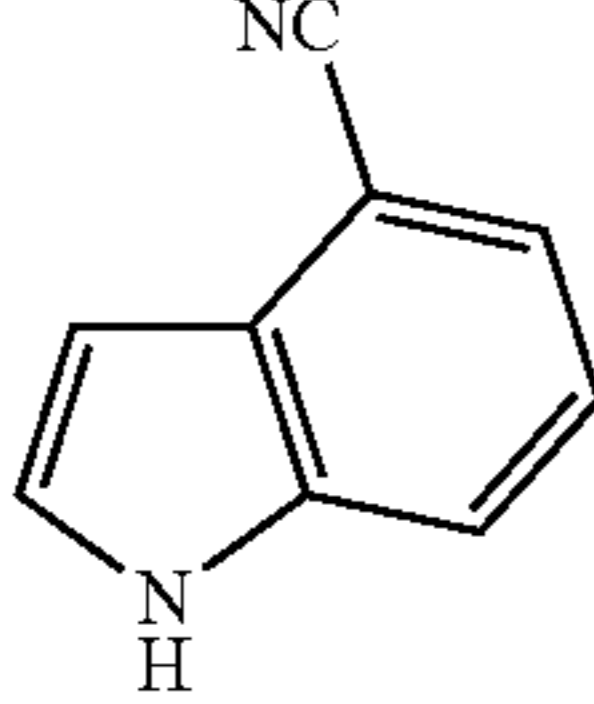
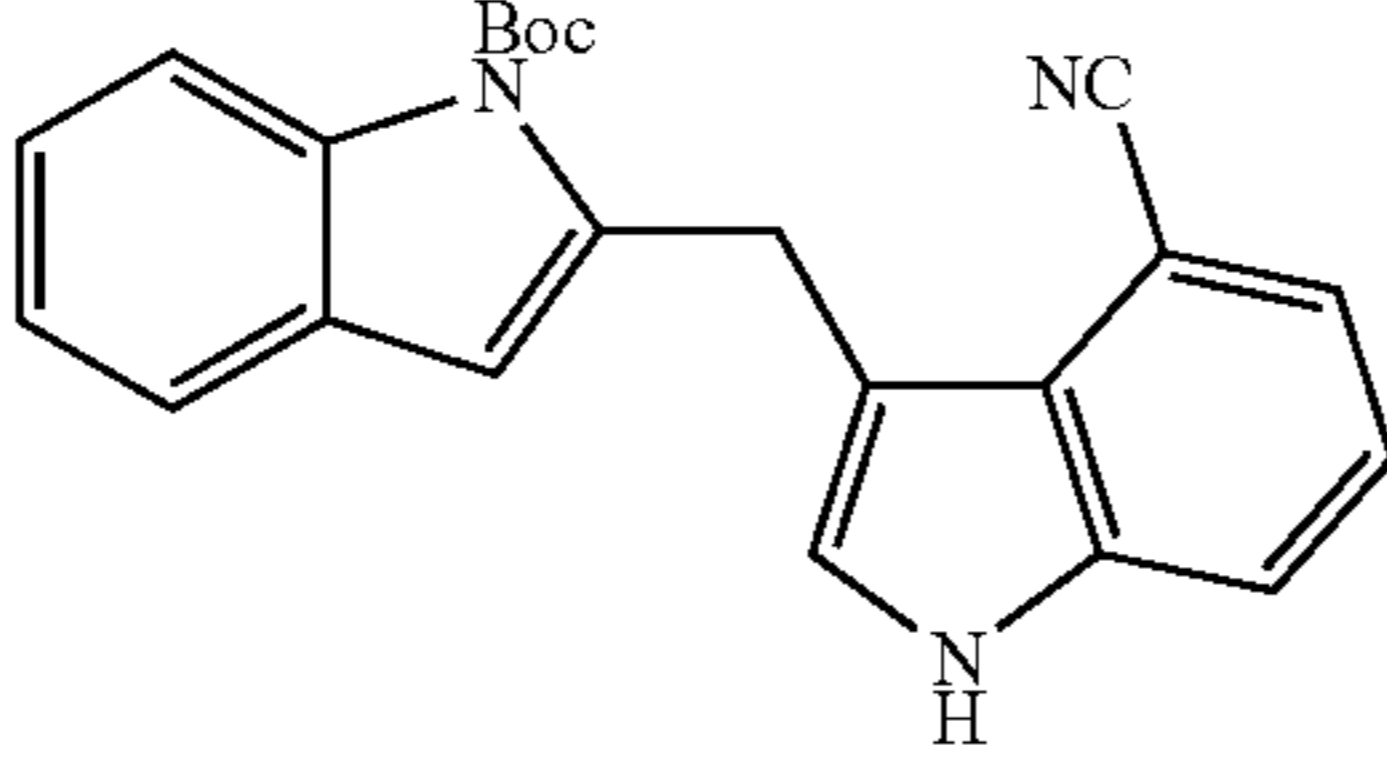
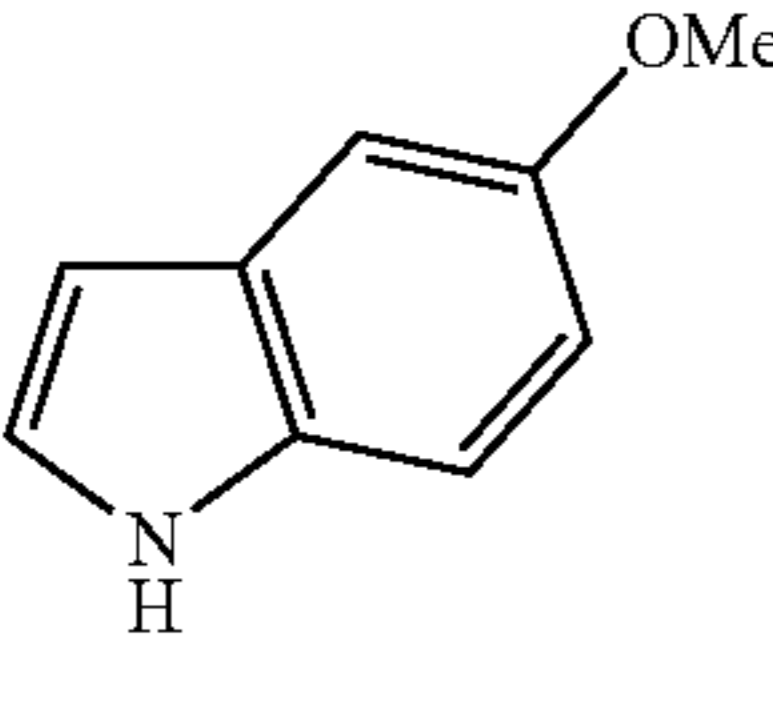
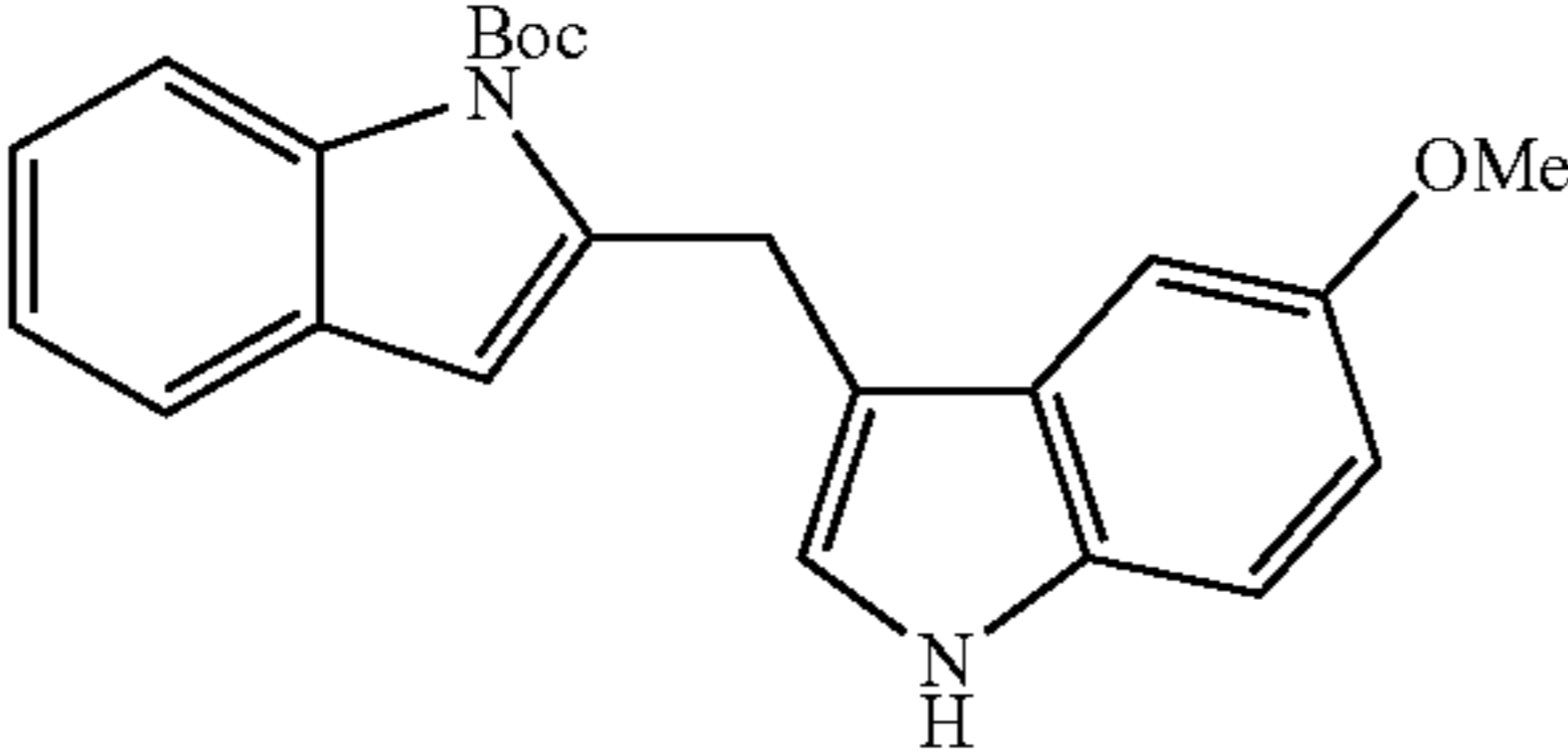
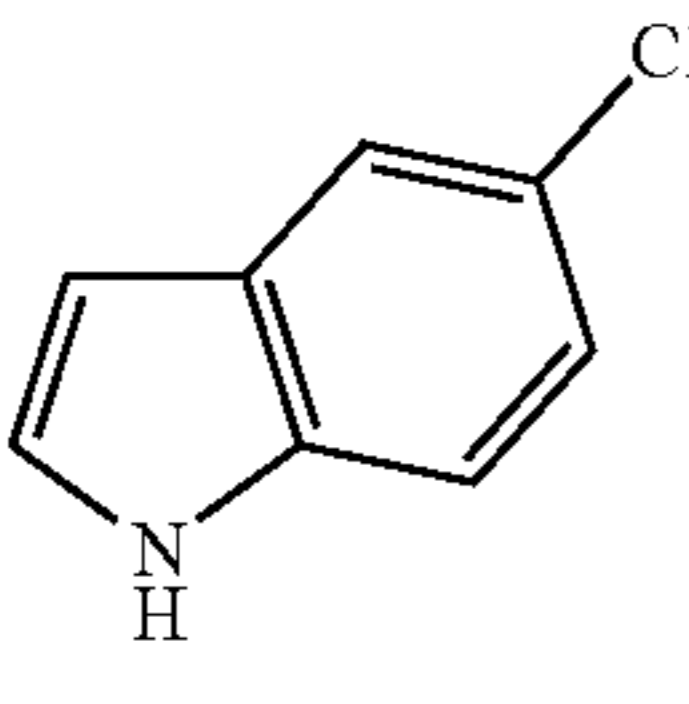
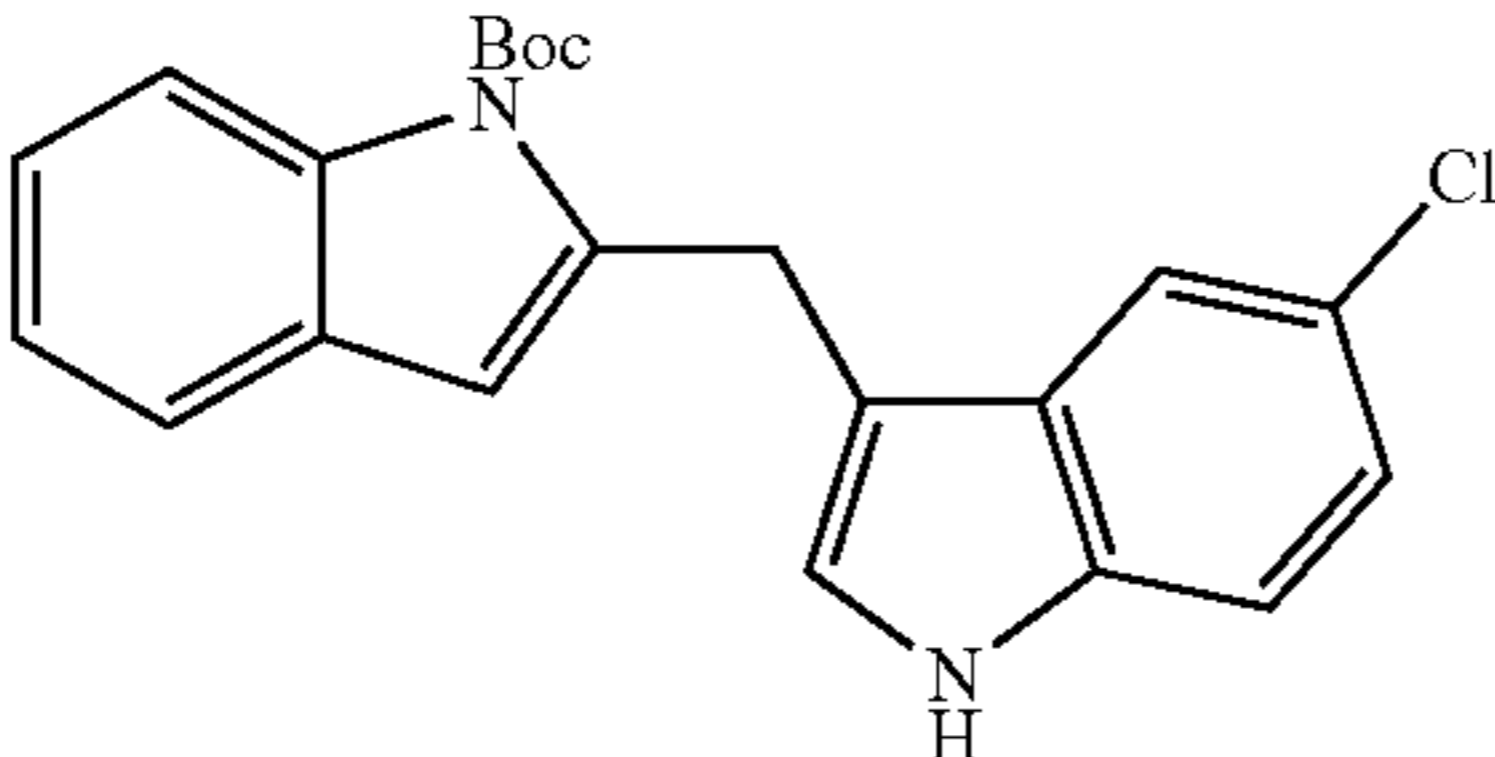
indole substrates	products	yield(%) <sup>b</sup>
5a 	6a 	83
5b 	6b 	88
5c 	6c 	68
5d 	6d 	81
5e 	6e 	77
5f 	6f 	84



TABLE 2-continued

Scope of Indoles for Pt-Catalyzed Tandem Indole Annulation/Arylation of Propargylic Ether 4<sup>a</sup>

indole substrates	products	yield(%) <sup>b</sup>
5g	6g	85
5h	6h	82
5i	6i	80
5j	6j	60

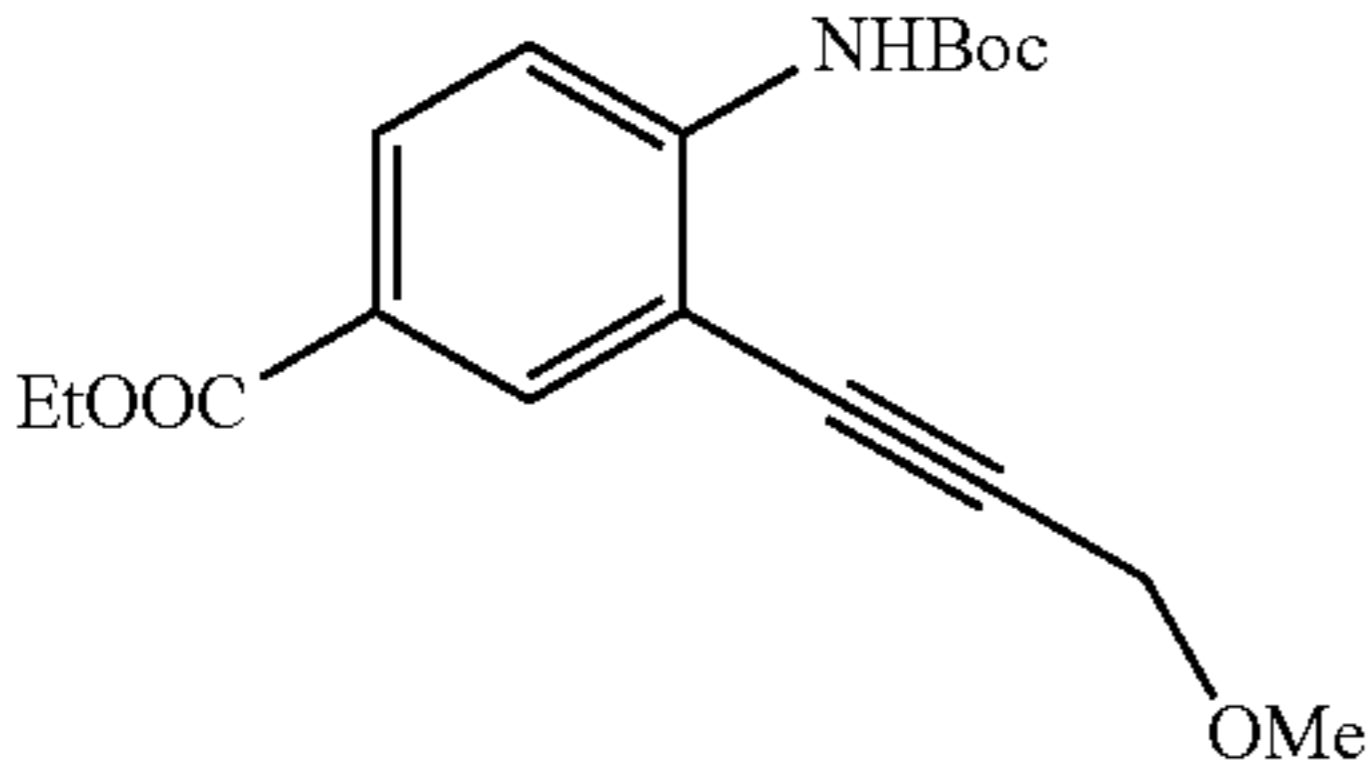
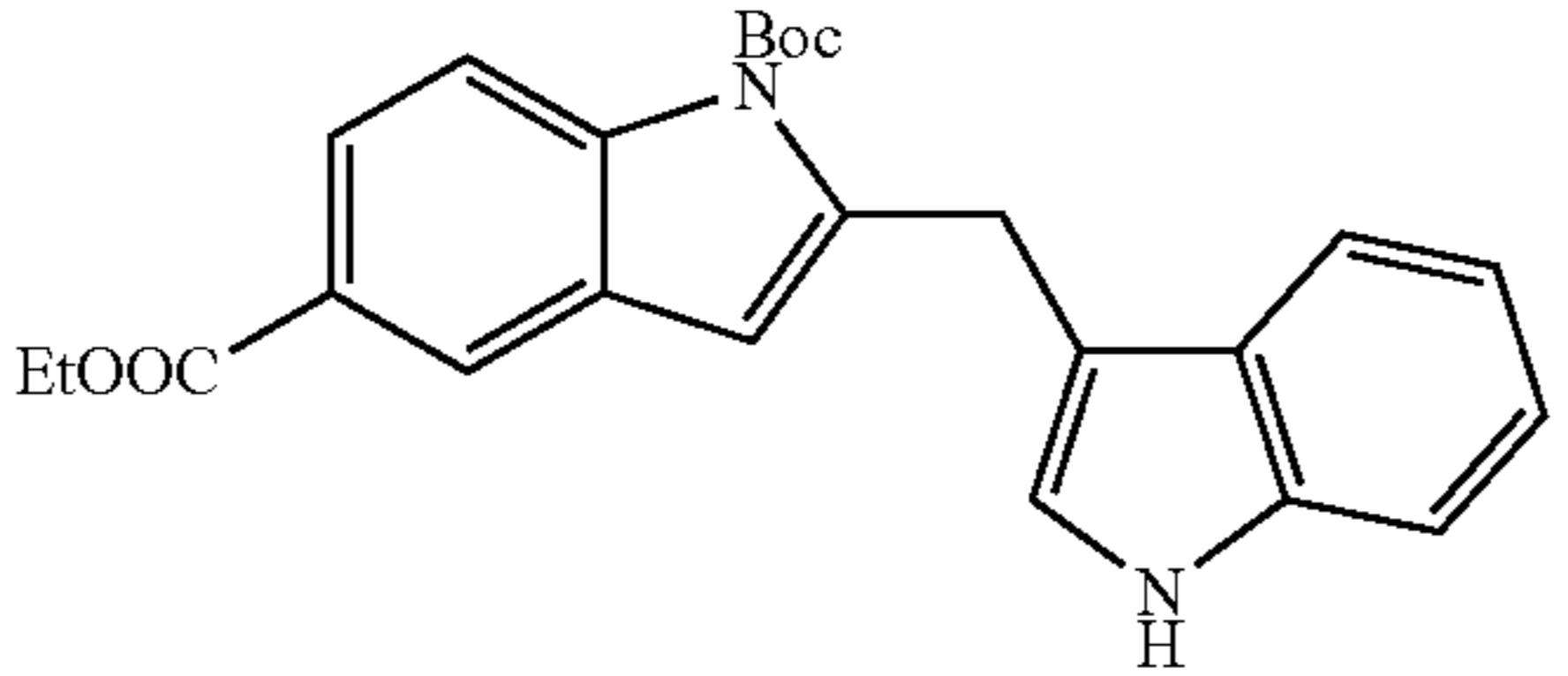
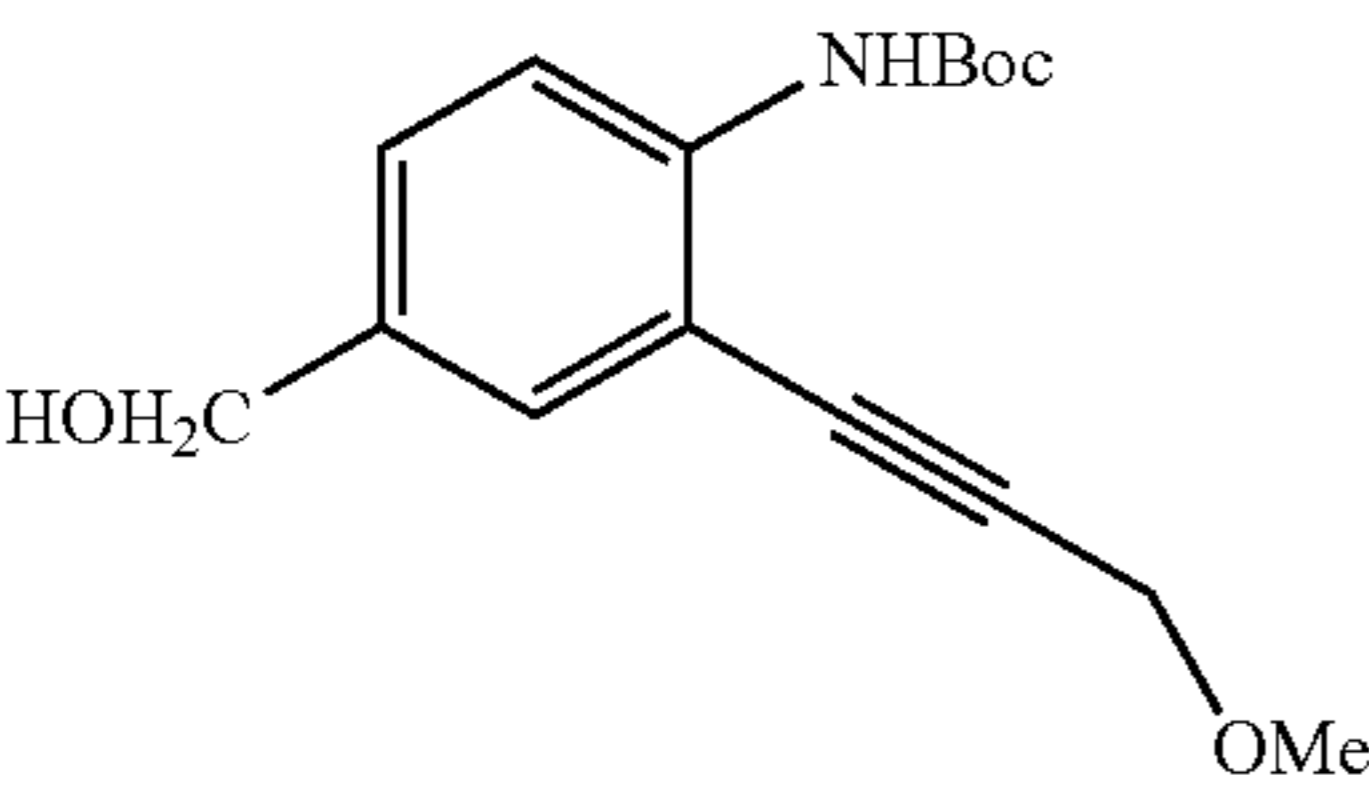
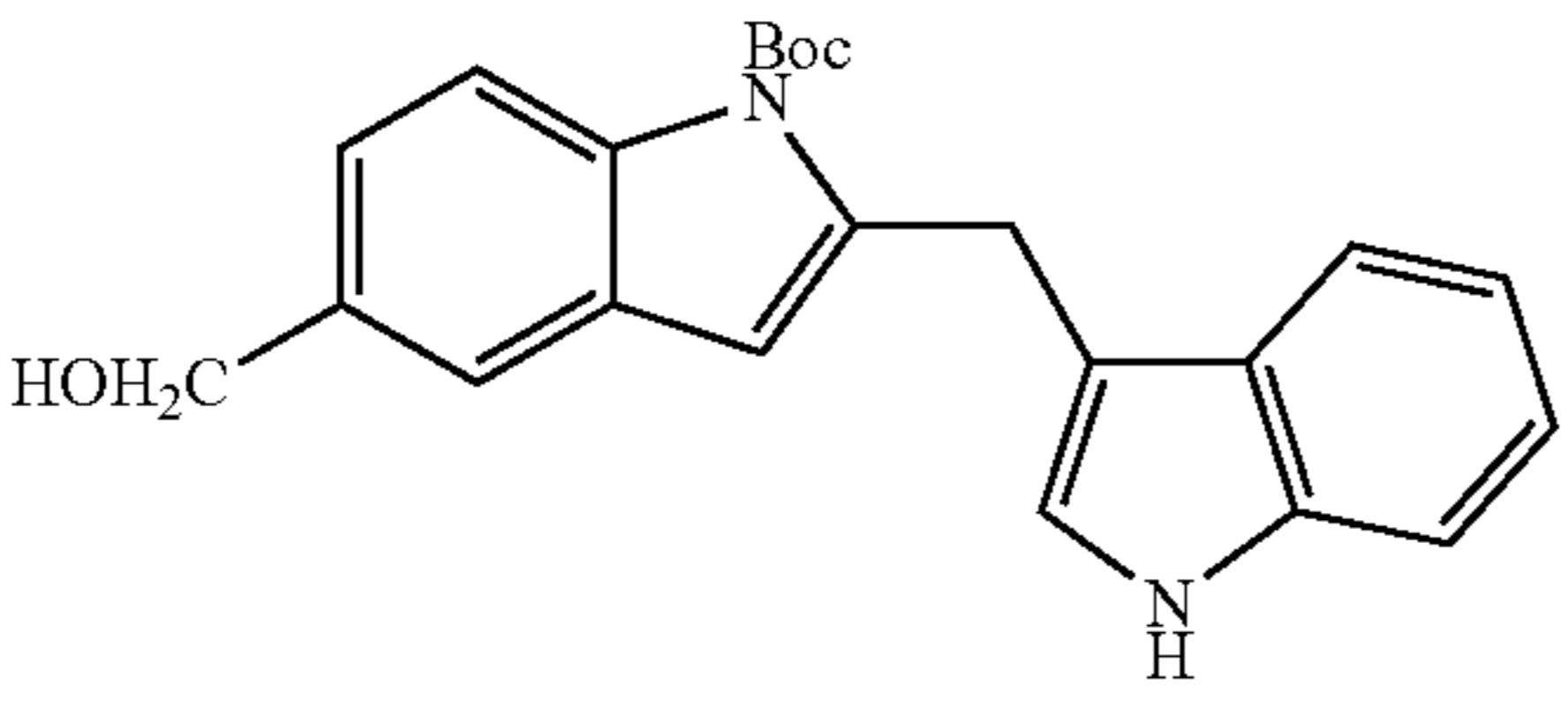
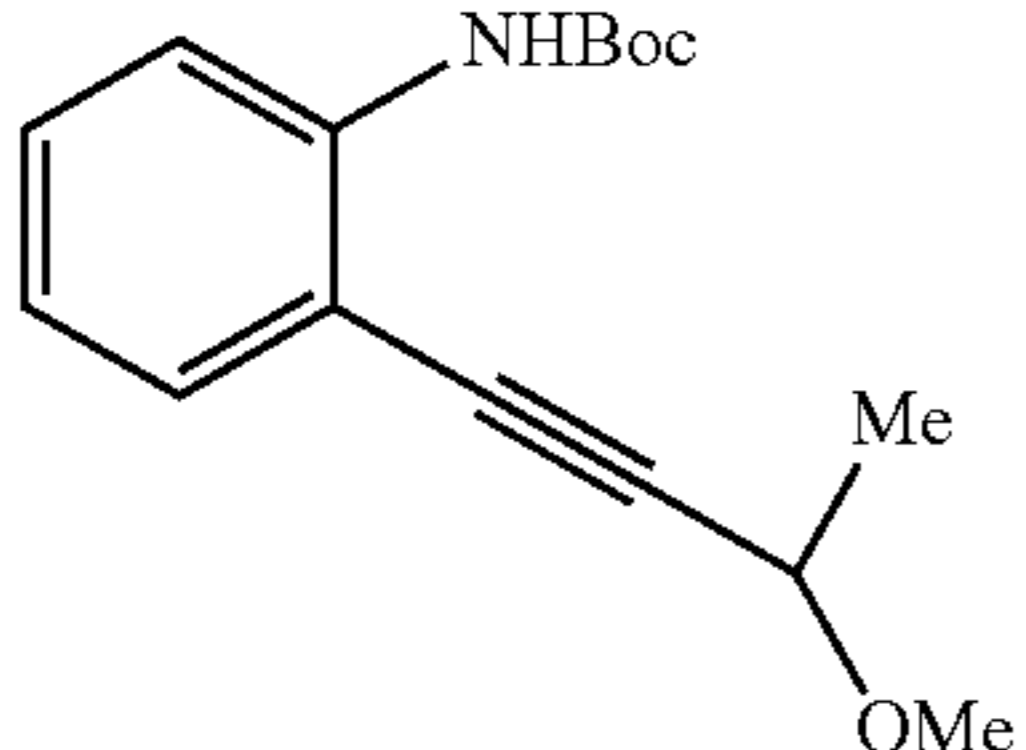
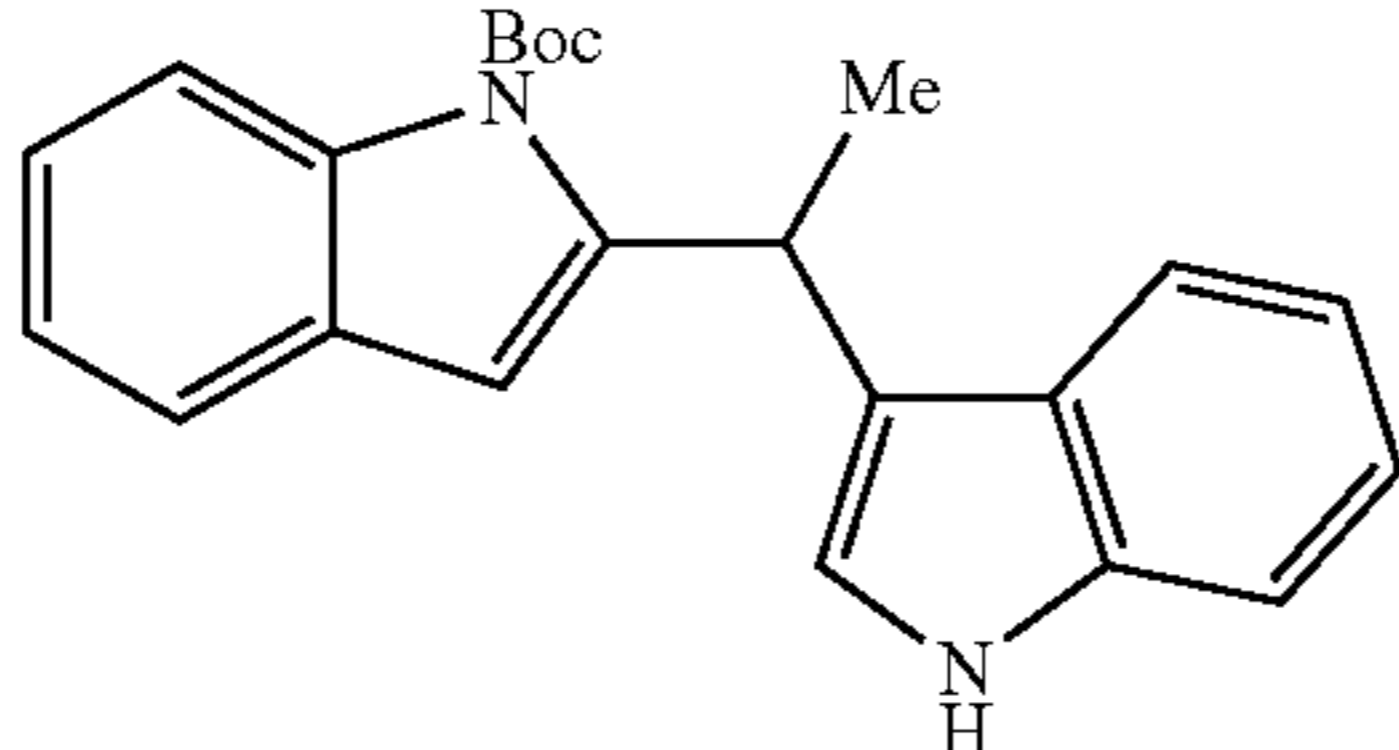
<sup>a</sup>Conditions: 4 (1 equiv), indole 5 (2 equiv), PtCl<sub>2</sub> (10 mol %), Na<sub>2</sub>CO<sub>3</sub> (1.5 equiv), 100° C., dioxane.<sup>b</sup>Isolated yield.

Table 3 shows that the method will also work when the propargylic ether is substituted at various positions on the aniline ring, as well as on the other side of the triple bond.

TABLE 3

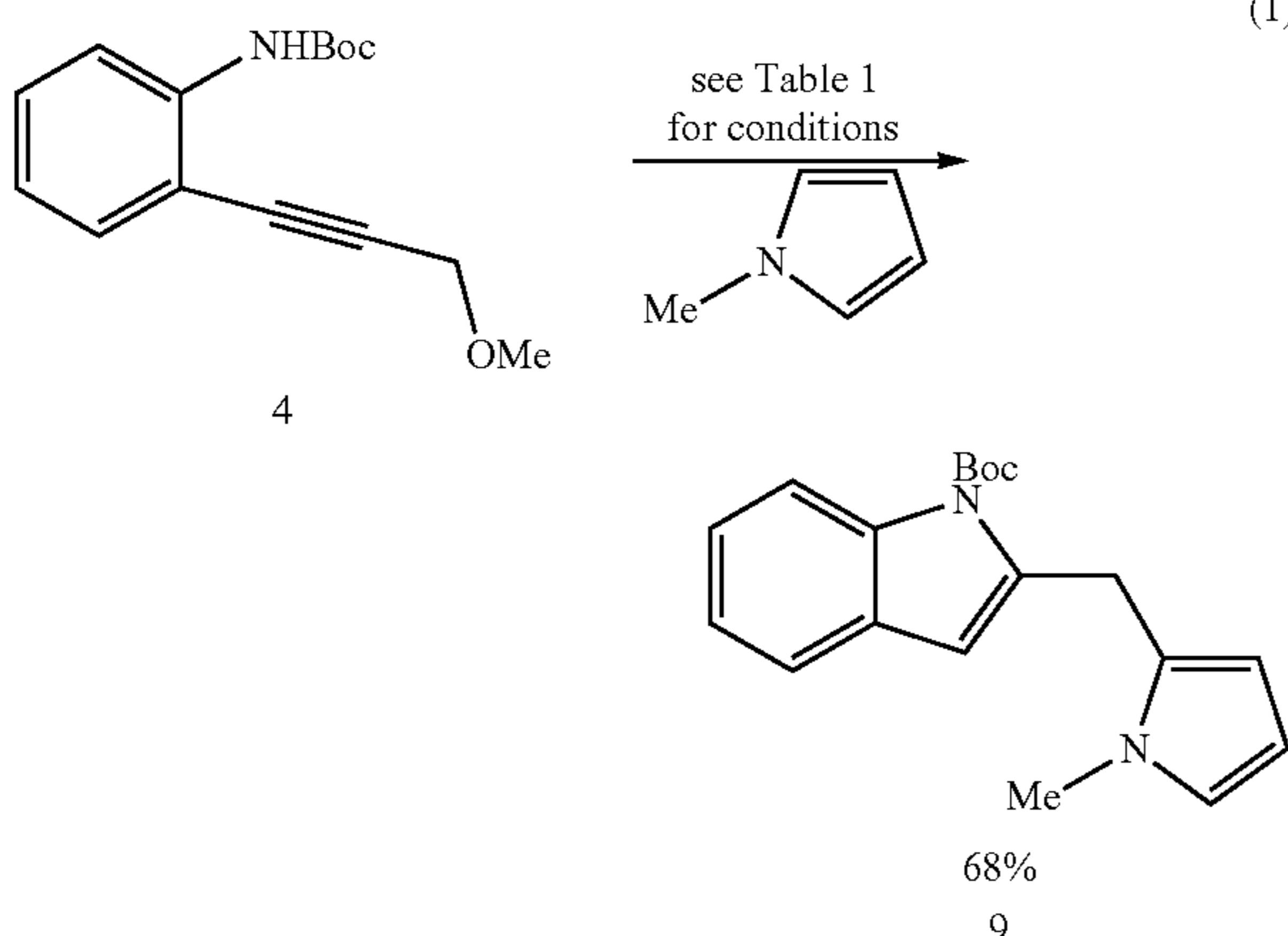
Scope of Aniline and Propargylic Ether for Pt-Catalyzed Tandem Indole Annulation/Arylation <sup>a</sup>		
indole substrates	products	yield <sup>b</sup>
7a	8a	77%

TABLE 3-continued

Scope of Aniline and Propargylic Ether for Pt-Catalyzed Tandem Indole Annulation/Arylation <sup>a</sup>		
indole substrates	products	yield <sup>b</sup>
7b 	8b 	62%
7c 	8c 	55%
7d 	8d 	70%

<sup>a</sup>See Table 1 for conditions.<sup>b</sup>Isolated yield.

Other nucleophiles beyond indoles will also function in the method. For example, substituted and unsubstituted pyrroles will also function in the method. N-methylpyrrole, for example, was used as the nucleophile and product 9 was isolated in 68% yield.

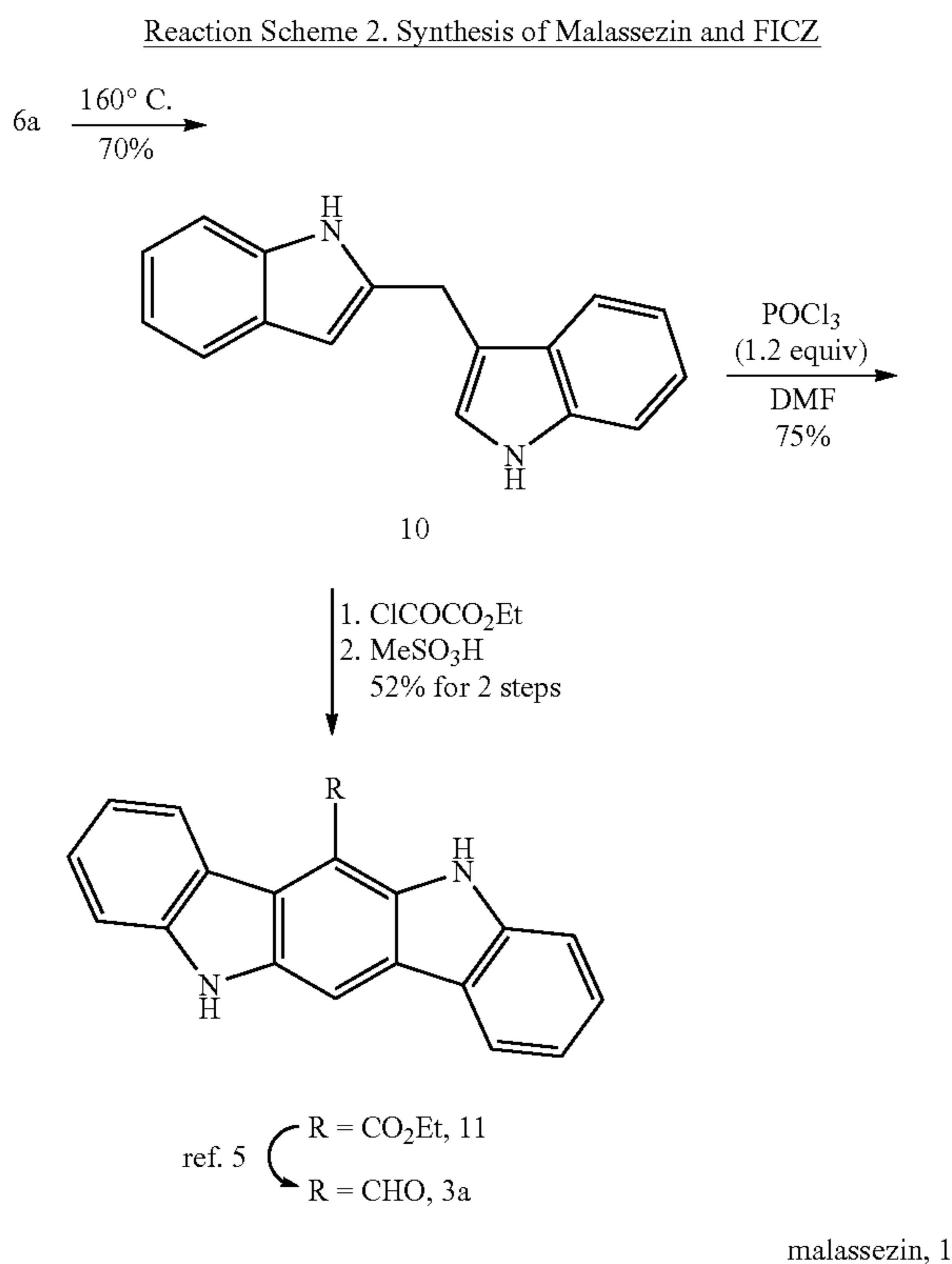


To demonstrate the utility of the Pt-catalyzed indole annulation/arylation method, it was used in the synthesis of the natural product malassezin and a formal synthesis of natural product FICZ as shown in Reaction Scheme 2. Removal of the Boc-protecting group in product 6a under thermal conditions yielded diindolylmethane 10, which

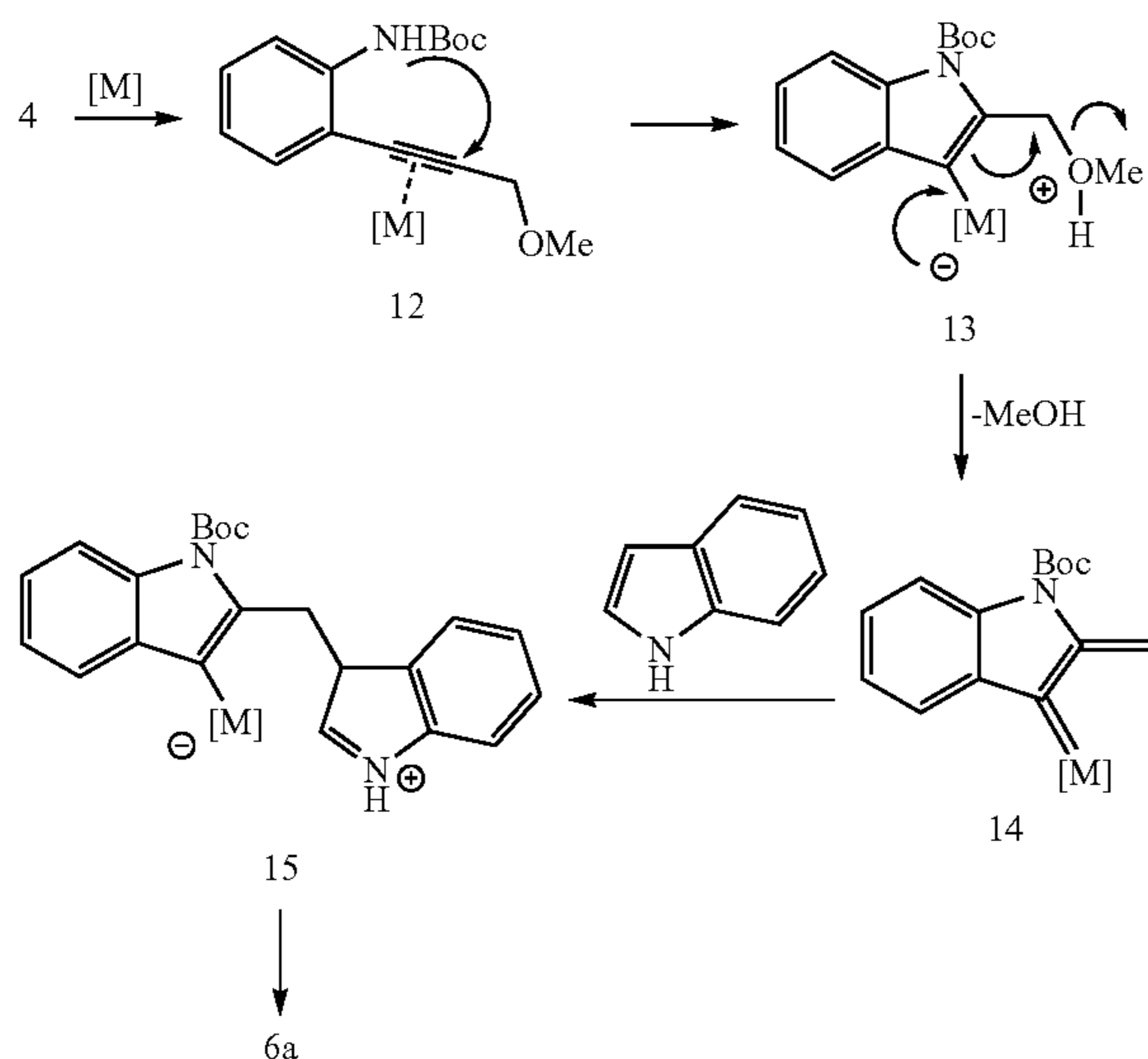
could undergo formylation to afford malassezin 1. Wille, G.; Maysers, P.; Thoma, W.; Monsees, T.; Baumgart, A.; Schmitz, H. J.; Schrenk, D.; Polborn, K.; Steglich, W. *Bioorg. Med. Chem.* 2001, 9, 955. Acylation of diindolylmethane 10 followed by acid-mediated cyclization produced indolo[3,2-b]carbazole 11, which has been converted to natural product FICZ 3a through a known sequence of reduction and oxidation. Wahlstrom, N.; Romero, I.; Bergman, J. *Eur. J. Org. Chem.* 2004, 2593. The spectroscopic data of compounds 1, 10 and 11 are all in accordance with literature (data not shown). The structure of 2,3'-diindolylmethane 6a was then further confirmed.

The proposed mechanism for the indole annulation/arylation is shown in Scheme 3. After the coordination of the metal catalyst to propargylic ether 4, 5-endo-cyclization of metal complex 12 will lead to the formation of indole intermediate 13. Elimination of a methanol can then produce metal carbene intermediate 14, which has been proposed previously by and others. Saito, K.; Sogou, H.; Suga, T.; Kusama, H.; Iwasawa, N. *J. Am. Chem. Soc.* 2011, 133, 689. Allegretti, P. A.; Ferreira, E. M. *Org. Lett.* 2011, 13, 5924. (c) Allegretti, P. A.; Ferreira, E. M. *Chem. Sci.* 2013, 4, 1053. This electrophilic metal carbene is then captured by an indole nucleophile to form adduct 15. Protonation and re-aromatization can then lead to final diindolylmethane product 5a. A (3+2) cycloaddition between metal carbene 14 and vinyl ethers has been reported. Saito, K.; Sogou, H.; Suga, T.; Kusama, H.; Iwasawa, N. *J. Am. Chem. Soc.* 2011, 133, 689. In the examples described herein, no (3+2) cycloaddition product between metal carbene 14 and indole was observed.

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Reaction Scheme 3. Proposed Mechanism



Thus, disclosed herein is an efficient method for the synthesis of various highly substituted 2,3'-diindolylmethanes and other compounds. The indole annulation event is accompanied by the coupling of two indole units. An electrophilic platinum carbene intermediate was proposed to be involved in this cascade reaction. It has been shown that the method can be applied to the synthesis of natural products malassezin and indolo[3,2-b]carbazoles.

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Nutritional and Pharmaceutical Compositions, Method to Treat Disease States Mediated by the Arylhydrocarbon Receptor (AhR), Including Prostate Cancer:

The present disclosure includes nutritional compositions.

5 Such compositions include any food or preparation for human consumption (including for enteral or parenteral consumption) which when taken into the body (a) serve to nourish or build up tissues or supply energy and/or (b) maintain, restore or support adequate nutritional status or metabolic function.

10 The nutritional composition comprises at least one compound as described herein and may either be in a solid or liquid form. Additionally, the composition may include edible macronutrients, vitamins and minerals in amounts desired for a particular use. The amount of such ingredients will vary depending on whether the composition is intended for use with normal, healthy infants, children or adults having specialized needs such as those which accompany hyperglycemic metabolic conditions.

20 Examples of macronutrients which may be added to the composition include but are not limited to edible fats, carbohydrates and proteins. Examples of such edible fats include but are not limited to coconut oil, soy oil, and mono- and diglycerides. Examples of such carbohydrates include but are not limited to glucose, edible lactose and hydrolyzed starch. Additionally, examples of proteins which may be utilized in the nutritional composition include but are not limited to soy proteins, electro-dialysed whey, electro-dialysed skim milk, milk whey, or the hydrolysates of these proteins.

30 With respect to vitamins and minerals, the following may be added to the nutritional compositions described herein: calcium, phosphorus, potassium, sodium, chloride, magnesium, manganese, iron, copper, zinc, selenium, iodine, and Vitamins A, E, D, C, and the B complex. Other such vitamins and minerals may also be added.

40 Examples of nutritional compositions disclosed herein include but are not limited to infant formulas, dietary supplements, dietary substitutes, and rehydration compositions. Nutritional compositions of particular interest include but are not limited to those utilized for enteral and parenteral supplementation for infants, specialist infant formulas, supplements for the elderly, and supplements for those with hyperglycemia.

45 The nutritional composition of the present invention may also be added to food even when supplementation of the diet is not required. For example, the composition may be added to food of any type including but not limited to margarines, modified butters, cheeses, milk, yoghurt, chocolate, candy, snacks, salad oils, cooking oils, cooking fats, meats, fish and beverages.

50 In a preferred version, the nutritional composition is an enteral nutritional product, more preferably, an adult or pediatric enteral nutritional product. This composition may be administered to adults or children experiencing stress or having specialized needs due to chronic or acute disease states. The composition may comprise, in addition to GLP-1 analogs described herein, macronutrients, vitamins and minerals as described above. The macronutrients may be present in amounts equivalent to those present in human milk or on an energy basis, i.e., on a per calorie basis.

65 Methods for formulating liquid or solid enteral and parenteral nutritional formulas are well known in the art. An enteral formula, for example, may be sterilized and subsequently utilized on a ready-to-feed (RTF) basis or stored in a concentrated liquid or powder. The powder can be prepared by spray drying the formula prepared as indicated

above, and reconstituting it by rehydrating the concentrate. Adult and pediatric nutritional formulas are well known in the art and are commercially available (e.g., Similac®-brand and Ensure®-brand formulas from Ross Products Division, Abbott Laboratories, Columbus, Ohio). A GLP-1 analog produced in accordance with the present disclosure may be added to commercial formulas of this type.

The energy density of the nutritional compositions in liquid form may range from about 0.6 Kcal to about 3 Kcal per ml. When in solid or powdered form, the nutritional supplements may contain from about 1.2 to more than 9 Kcals per gram, preferably about 3 to 7 Kcals per gm. In general, the osmolality of a liquid product should be less than 700 mOsm and, more preferably, less than 660 mOsm.

Also disclosed herein are pharmaceutical compositions comprising one or more of the compounds or a pharmaceutically suitable salt thereof as described herein. The pharmaceutical compositions are useful to treat disease states mediated by the arylhydrocarbon receptor (AhR). More specifically, the pharmaceutical composition may comprise one or more of the compounds disclosed herein as well as a standard, well-known, non-toxic pharmaceutically suitable carrier, adjuvant or vehicle such as, for example, phosphate-buffered saline, water, ethanol, polyols, vegetable oils, a wetting agent or an emulsion such as a water/oil emulsion. The composition may be in either a liquid, solid or semi-solid form. For example, the composition may be in the form of a tablet, capsule, ingestible liquid or powder, injectible, suppository, or topical ointment or cream. Proper fluidity can be maintained, for example, by maintaining appropriate particle size in the case of dispersions and by the use of surfactants. It may also be desirable to include isotonic agents, for example, sugars, sodium chloride, and the like. Besides such inert diluents, the composition may also include adjuvants, such as wetting agents, emulsifying and suspending agents, sweetening agents, flavoring agents, perfuming agents, and the like.

Suspensions, in addition to the active compounds, may comprise suspending agents such as, for example, ethoxylated isostearyl alcohols, polyoxyethylene sorbitol and sorbitan esters, microcrystalline cellulose, aluminum metahydroxide, bentonite, agar-agar and tragacanth or mixtures of these substances.

Solid dosage forms such as tablets and capsules can be prepared using techniques well known in the art of pharmacy. For example, one or more compounds produced as described herein can be tableted with conventional tablet bases such as lactose, sucrose, and cornstarch in combination with binders such as acacia, cornstarch or gelatin, disintegrating agents such as potato starch or alginic acid, and a lubricant such as stearic acid or magnesium stearate. Capsules can be prepared by incorporating these excipients into a gelatin capsule along with antioxidants and the relevant active ingredient(s) as described herein.

For intravenous administration, the compounds may be incorporated into commercial formulations such as Intralipid®-brand fat emulsions for intravenous injection. ("Intralipid" is a registered trademark of Fresenius Kabi AB, Uppsalla, Sweden.) Where desired, the individual components of the formulations may be provided individually, in kit form, for single or multiple use. A typical intravenous dosage of a representative compound as described herein is from about 0.1 mg to 100 mg daily and is preferably from 0.5 mg to 3.0 mg daily. Dosages above and below these stated ranges are specifically within the scope of the claims.

Possible routes of administration of the pharmaceutical compositions include, for example, enteral (e.g., oral and

rectal) and parenteral. For example, a liquid preparation may be administered, for example, orally or rectally. Additionally, a homogenous mixture can be completely dispersed in water (or other suitable vehicle), admixed under sterile conditions with physiologically acceptable diluents, preservatives, buffers or propellants in order to form a spray or inhalant. The route of administration will, of course, depend upon the desired effect and the medical state of the subject being treated. The dosage of the composition to be administered to the patient may be determined by one of ordinary skill in the art and depends upon various factors such as weight of the patient, age of the patient, immune status of the patient, etc., and is ultimately at the discretion of the medical professional administering the treatment.

With respect to form, the composition may be, for example, a solution, a dispersion, a suspension, an emulsion, or a sterile powder which is then reconstituted. The composition may be administered in a single daily dose or multiple doses.

The present disclosure also includes treating neoplastic disorders in mammals, including humans, by administering an anti-neoplastic-effective amount of one or more the compounds described herein. In particular, the compositions of the present invention may be used to treat neoplasms of any and all description, but most specifically those that involve a signaling pathway mediated by AhR, and most specifically prostate cancer. Additionally, the compositions of the present invention may also be used to prevent the apoptotic death of cells in the prostate.

It should be noted that the above-described pharmaceutical and nutritional compositions may be utilized in connection with non-human animals, both domestic and non-domestic, as well as humans.

### Examples

The following examples are included solely to provide a more complete disclosure of the methods, compounds, and compositions described herein. The examples are not intended to limit the scope of the disclosure or the attached claims

#### 1. General Remarks:

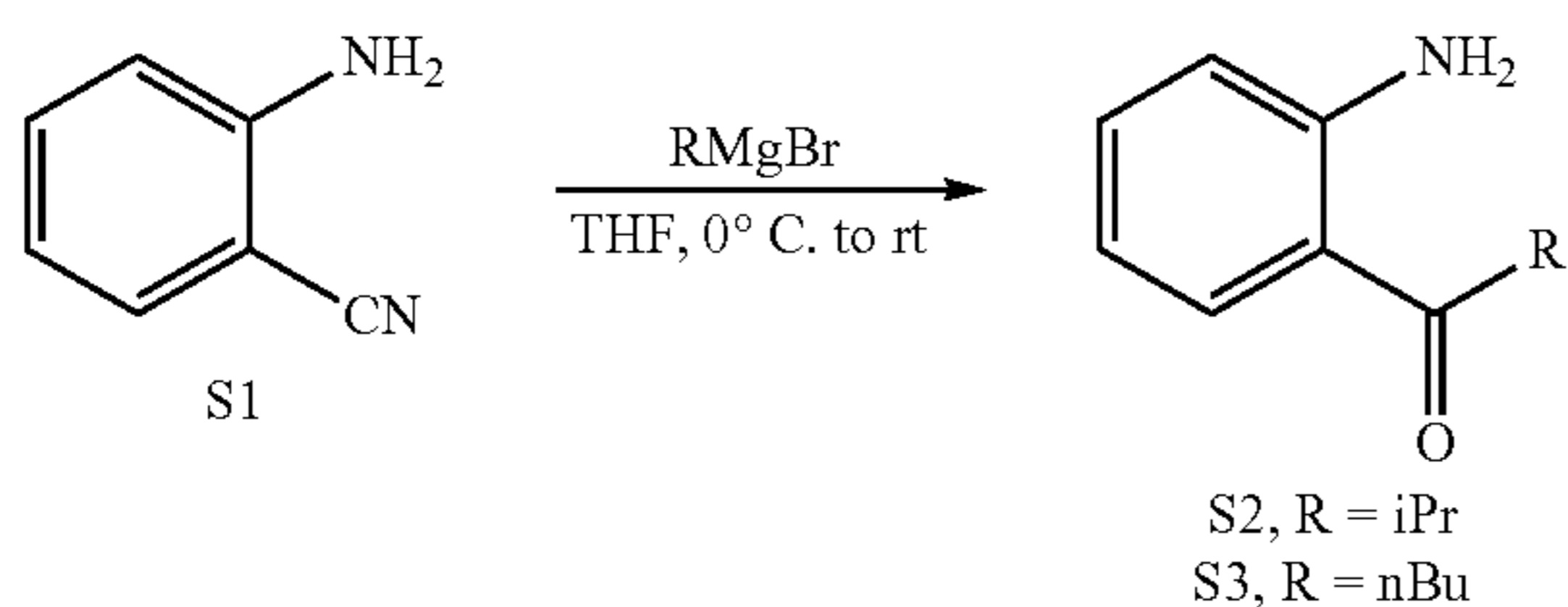
All reactions in non-aqueous media were conducted under a positive pressure of dry argon in glassware that had been oven dried prior to use unless noted otherwise. Anhydrous solutions were transferred via an oven dried syringe or cannula. All solvents were dried prior to use unless noted otherwise. Thin layer chromatography was performed using precoated silica gel plates (EMD Chemicals Inc., Gibbstown, N.J. USA, catalog no. 60, F254). Flash column chromatography was performed with silica gel (SiliCycle, Inc., Quebec City (Quebec), Canada; 40-63  $\mu\text{m}$ ). Infrared spectra (IR) were obtained on a Bruker Equinox 55 Spectrophotometer (Bruker AXS, Inc., Madison, Wis., USA).  $^1\text{H}$  and  $^{13}\text{C}$  nuclear magnetic resonance spectra (NMR) were obtained on a Varian Unity-Inova (Varian Instruments, a division of Agilent Technologies, Inc., Santa Clara, Calif., USA) 400 MHz or 500 MHz recorded in ppm ( $\delta$ ) downfield of TMS ( $\delta=0$ ) in  $\text{CDCl}_3$  unless noted otherwise. Signal splitting patterns were described as singlet (s), doublet (d), triplet (t), quartet (q), quintet (quint), or multiplet (m), with coupling constants (J) in hertz. High resolution mass spectra (HRMS) were performed by Analytical Instrument Center at the School of Pharmacy on an Electron Spray Injection (ESI) mass spectrometer. The optical rotation was determined using a Perkin-Elmer 241 Polarimeter (PerkinElmer, Inc. Waltham, Mass., USA).

35

## 2. Experimental Procedure for the Preparation of Propargylic Alcohol Substrates:

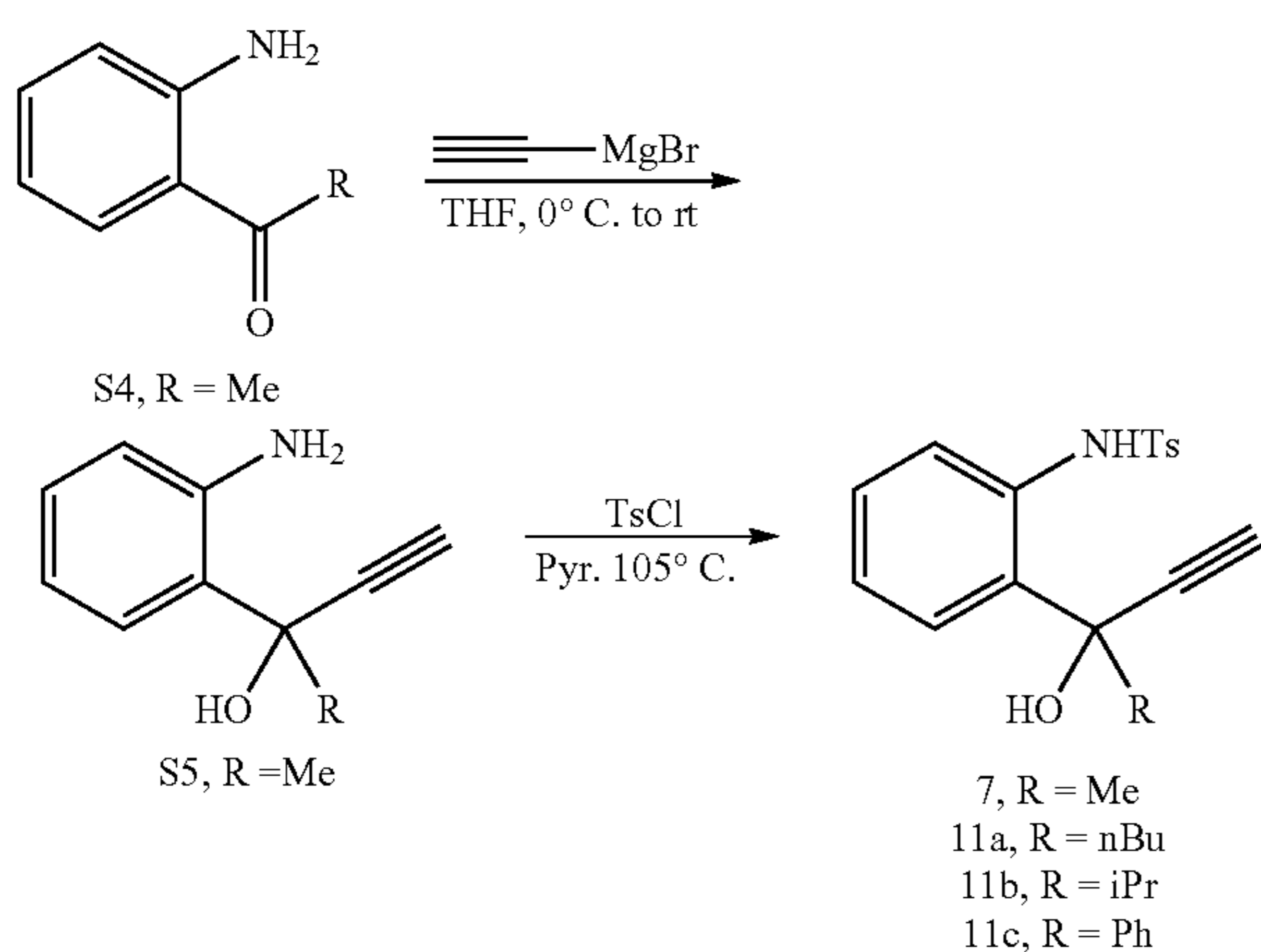
Preparation of Substrates 7 and 11a-11c:

(2.1) Ketones S2 and S3 were Prepared from S1.



To a solution of 2-aminobenzonitrile S1 (0.50 g, 4.2 mmol) in THF (4 mL) was added isopropylmagnesium bromide (16.8 mL, 0.5 M in THF, 8.4 mmol) at 0° C. over 5 min. The reaction was then allowed to warm to ambient temperature and stir at this temperature for 1 h. The reaction was quenched by slow addition of 1 M HCl. The mixture was extracted by EtOAc. The combined organic layers was washed with NaHCO<sub>3</sub> and brine, dried over Na<sub>2</sub>SO<sub>4</sub>, and concentrated under vacuum. The residue was purified by flash column chromatography (10-30% EtOAc in hexanes) to give S2 (0.60 g, 88%) as colorless oil. Zhang, J.; Zhu, D.; Yu, C.; Wan, C.; Wang, Z., *Org. Lett.* 2010, 12, 2841. Gabriele, B.; Mancuso, R.; Lupinacci, E.; Spina, R.; Salerno, G.; Veltri, L.; Dibenedetto, A. *Tetrahedron* 2009, 65, 8507. Clavier, H.; Lepronier, A.; Bengobesse-Mintsa, N.; Gatineau, D.; Pellissier, H.; Giordano, L.; Tenaglia, A.; Buono, G. *Adv. Synth. Catal.* 2013, 355, 403. Kothandaraman, P.; Lauw, S. J. L.; Chan, P. W. H. *Tetrahedron*, 2013, 69, 7471.

Following the same procedure, S3 was prepared from S1 in 44.3 mmol scale (4.61 g, 59%) as colorless oil.



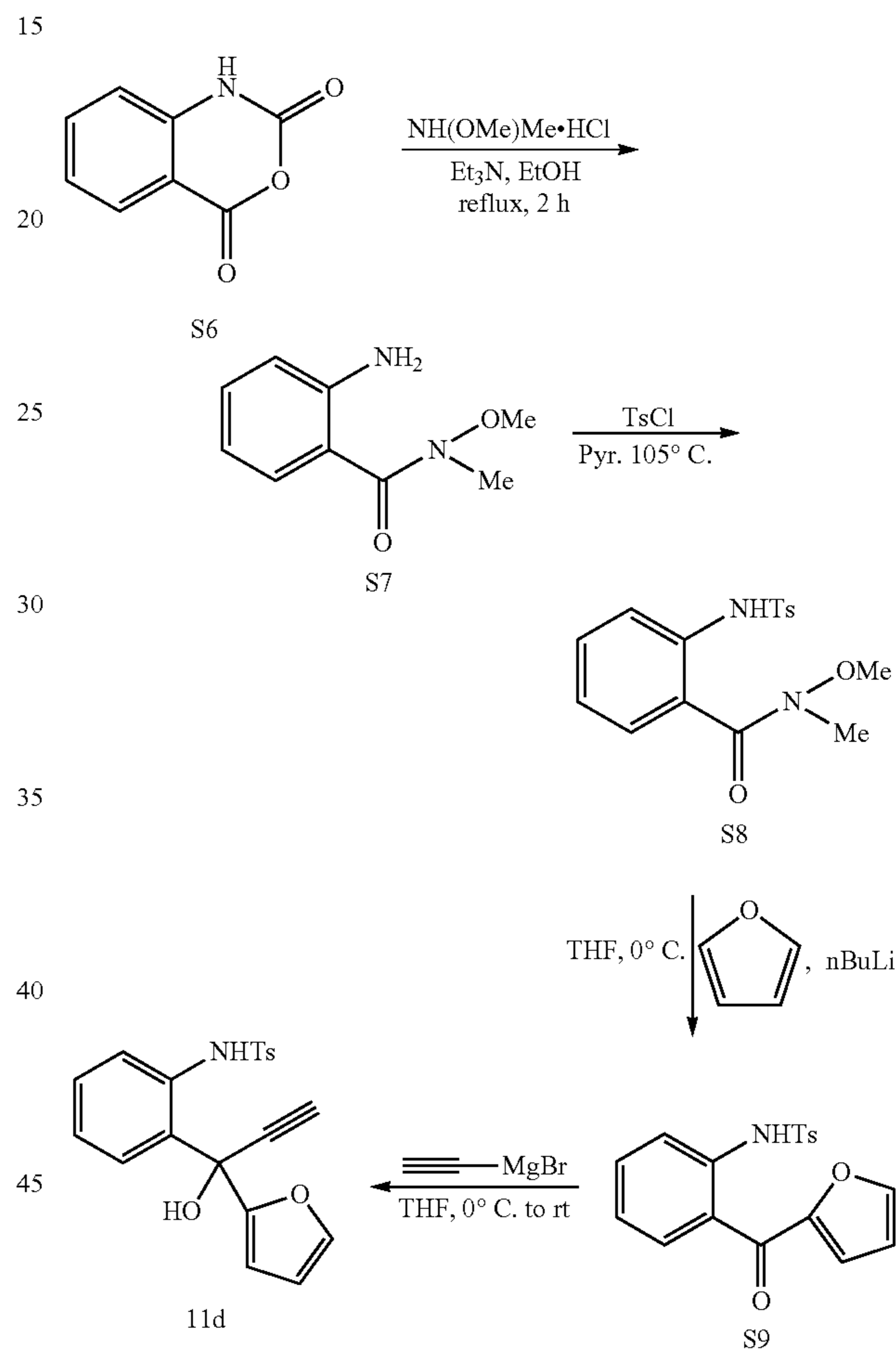
Commercially available 1-(2-aminophenyl)ethanone S4 (2.12 g, 15.7 mmol) was dissolved in dry THF (100 mL). To the above solution was added ethynylmagnesium bromide (157 mL, 0.5 M in THF, 78.5 mmol) at 0° C. over 30 min with stirring. After additional stirring at 0° C. for 15 min, the mixture was allowed to warm up to room temperature, and stirred over night. The reaction was quenched by saturated aqueous NH<sub>4</sub>Cl. The mixture was extracted with EtOAc and the combined organic layers were washed with brine and dried over Na<sub>2</sub>SO<sub>4</sub>. The solvent was removed under vacuum and the crude product S5 was directly used for the next step.

36

To a solution of crude S5 was added tosyl chloride (1.05 equiv) in pyridine (0.8 M) and the resulting solution was stirred at 105° C. for 30 min under argon. The reaction mixture was cooled to room temperature and diluted with EtOAc. The mixture was washed with 3 M HCl and brine, dried over Na<sub>2</sub>SO<sub>4</sub> and concentrated under vacuum. The resulting residue was purified with flash column chromatography (10-30% EtOAc in hexanes) to give the pure product 7 (2.56 g, 62% for two steps) as white solid.

Other substrates were prepared following the same procedure. 11a (0.69 g, 48%); 11b (0.94 g, 69%); 11c (1.87 g, 56%). Kothandaraman, P.; Rao, W.; Foo, S. J.; Chan, P. W. H. *Angew. Chem. Int. Ed.* 2010, 49, 4619.

(2.2) Preparation of Substrate 11d:



To a solution of N,O-dimethylhydroxylamine hydrochloride (14.6 g, 0.15 mol) in 90% aqueous ethanol (57 mL) was added triethylamine (20.8 mL, 0.15 mol) and after 10 min of stirring at room temperature. To the above solution was added isatonic anhydride S6 (16.3 g, 0.1 mol) in several portions. The reaction was then heated at reflux for 2 h and poured onto an equal volume of ice and saturated aqueous Na<sub>2</sub>CO<sub>3</sub>. The ethanol was then removed under vacuum and the resulting aqueous mixture was extracted with EtOAc. The combined organic layers were washed with water and brine, dried over Na<sub>2</sub>SO<sub>4</sub> and concentrated. The resulting residue was purified by column chromatography on silica gel (10-30% EtOAc in hexanes) to give S7 as a yellow oil (14.4 g, 80%).

Following the same procedure for the preparation of 7 from S5, we prepared S8 from S7 in 50 mmol scale to obtain (8.16 g, 49%) of the product.

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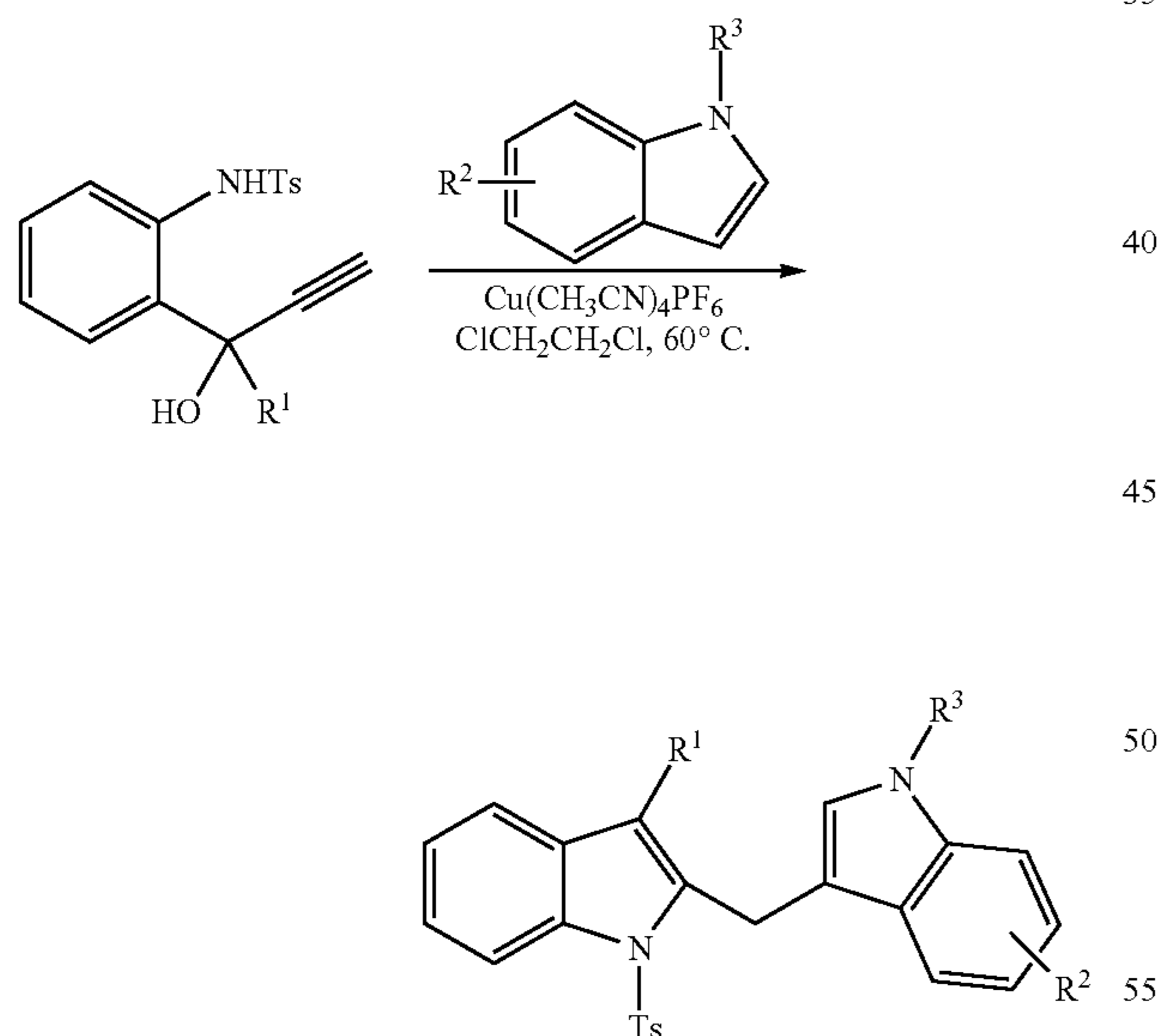
We adapted literature procedure for the preparation of S9. Kothandaraman, P.; Rao, W.; Foo, S. J.; Chan, P. W. H. *Angew. Chem. Int. Ed.* 2010, 49, 4619. To a solution of furan (0.48 mL, 6.0 mmol) in THF (20 mL) was added nBuLi (1.2 mL, 2.5 M in hexanes, 3.0 mmol) dropwise at  $-78^{\circ}\text{C}$ . The solution was then allowed to warm to rt and stirred over night. The solution was then cooled to  $0^{\circ}\text{C}$ . To this solution was added S8 (0.67 g, 2.0 mmol) in THF (2 mL). After the addition was complete, the reaction was stirred at  $0^{\circ}\text{C}$  for 4 h. Reaction was diluted with EtOAc and quenched with saturated aqueous  $\text{NH}_4\text{Cl}$ . The aqueous phase was extracted with EtOAc and the combined organic layers were washed with brine and dried over  $\text{Na}_2\text{SO}_4$ . The solvent was removed under vacuum and the resulting residue was purified by flash column chromatography (10-30% EtOAc in hexanes) to give product S9 (0.61 g, 89%) as colorless oil.

Following the same procedure for the preparation of S5 from S4, we prepared 11d from S9 in 0.59 mmol scale to obtain (0.18 g, 67%) of the product.

### 3. General Procedures for the Pt-Catalyzed Tandem Indole Annulation/Arylation:

To an oven-dried flask was added  $\text{PtCl}_2$  (10 mol %),  $\text{Na}_2\text{CO}_3$  (1.5 equiv), indole 5 (2.0 equiv), 4 (1.0 equiv) and dioxane (0.2 M for 4). The flask was degassed with Ar, sealed and heated to  $100^{\circ}\text{C}$  overnight. After the reaction was completed, the solvent was evaporated under reduced pressure. The residue was purified by flash column chromatography on silica gel.

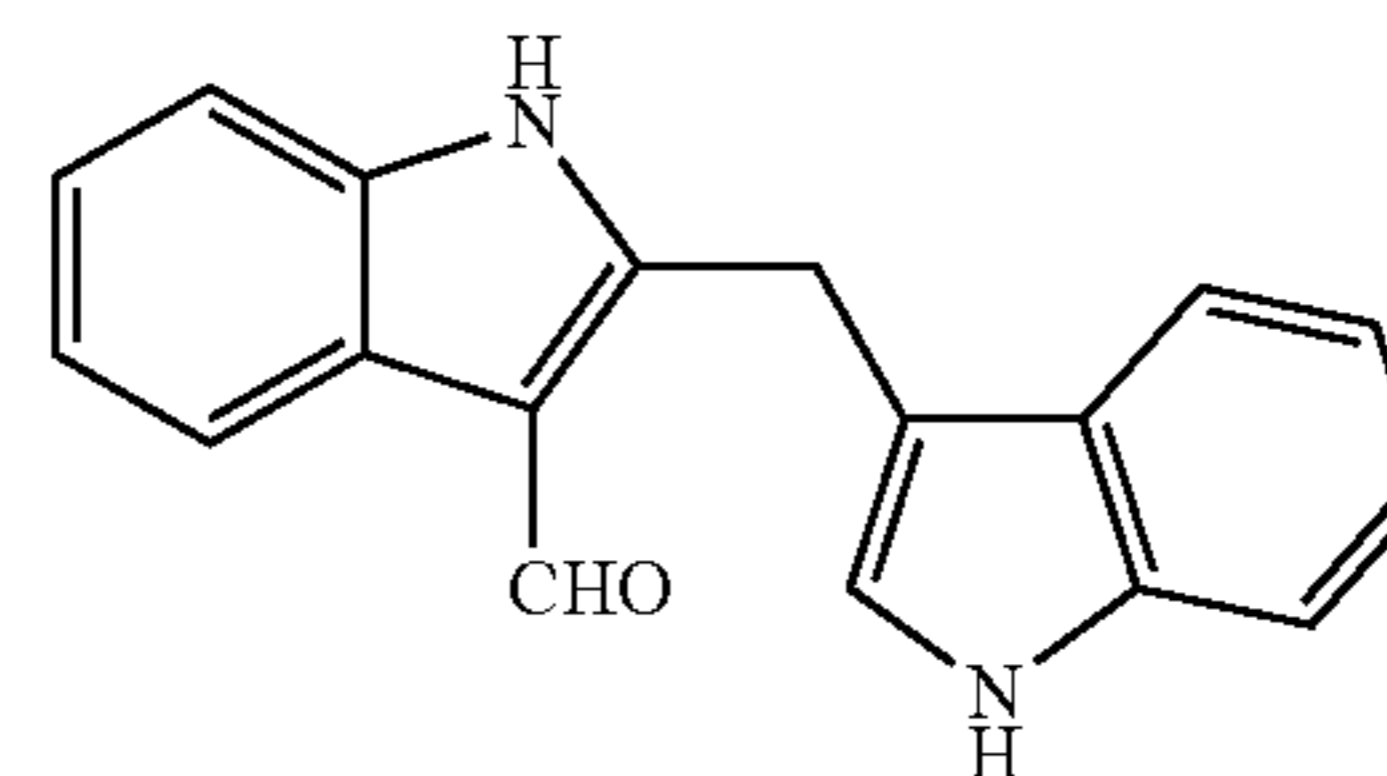
### 4. General Experimental Procedure for the Preparation of Diindolylmethanes:



Propargylic alcohol (1.0 equiv) and tetrakis(acetonitrile) copper (I) hexafluorophosphate (10 mol %) were dissolved in 1,2-dichloroethane (0.1 M). To the above solution was added indole substrate (2.0 equiv). The mixture was stirred under argon at  $60^{\circ}\text{C}$  for overnight. After the reaction was completed, the solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (5% to 20% EtOAc in hexanes) to give the corresponding diindolylmethane.

38

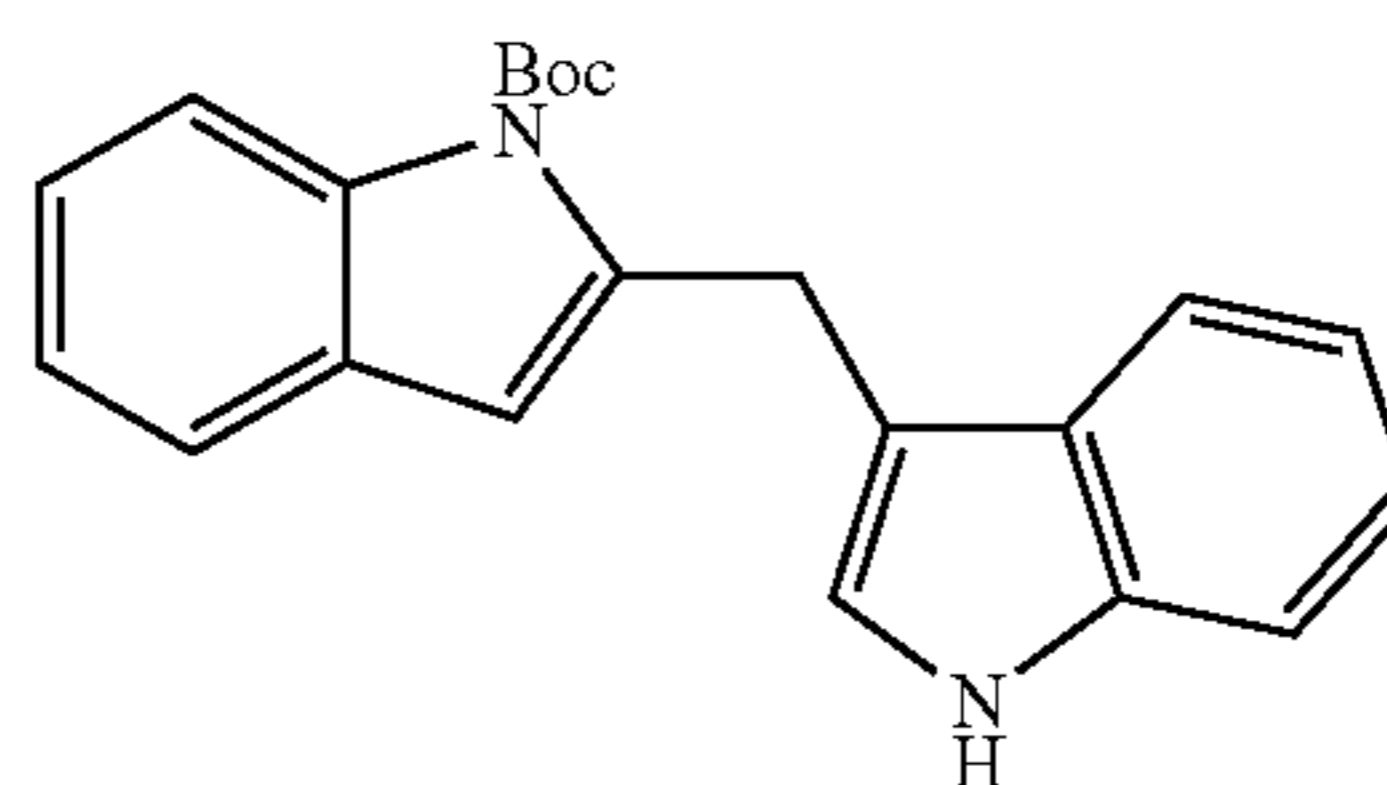
### 5. Characterization Data for New Compounds:



2-((1H-indol-3-yl)methyl)-1H-indole-3-carbaldehyde

To 0.3 mL of DMF was added  $\text{POCl}_3$  (10  $\mu\text{l}$ , 0.11 mmol) dropwise over 5 min at  $0^{\circ}\text{C}$ . After 10 min, a solution of bisindole 10 (25 mg, 0.1 mmol) in 0.2 ml of DMF was added. The solution was stirred at room temperature overnight and was poured into  $\text{NaHCO}_3$  solution, extracted with ether, washed with 0.1 M  $\text{NaOH}$  solution, dried over  $\text{MgSO}_4$  and purified by flash column chromatography (Hexane/EtOAc=1.5:1) to provide a pinkish solid (20.5 mg, 75% yield, m.p.= $235-236^{\circ}\text{C}$ ).

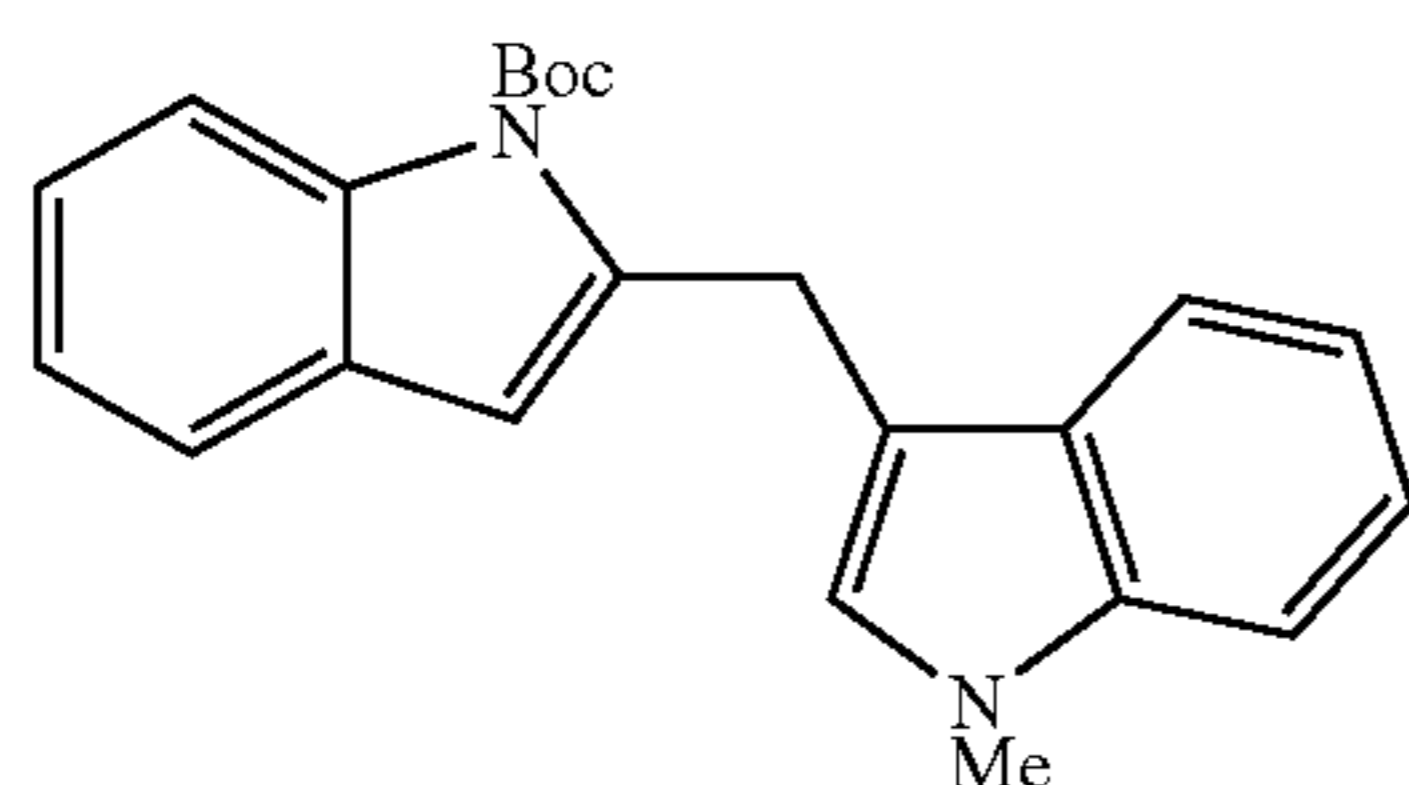
$^1\text{H}$  NMR (400 MHz,  $\text{CCl}_4$ : $\text{DMSO-d}_6$ =1:4):  $\delta$  4.52 (s, 2H), 6.92 (t,  $J=6.8$  Hz, 1H), 7.03 (t,  $J=7.2$  Hz, 1H), 7.11 (m, 2H), 7.21 (s, 1H), 7.33 (m, 2H), 7.47 (d,  $J=8.0$  Hz, 1H), 8.03 (m, 1H), 10.23 (s, 1H), 10.92 (br, 1H), 11.85 (br, 1H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CCl}_4$ : $\text{DMSO-d}_6$ =1:4): 185.1, 152.0, 137.1, 136.3, 127.4, 126.4, 124.5, 123.4, 122.6, 122.0, 121.1, 119.4, 119.0, 113.9, 112.5, 112.3, 111.6, 22.9. IR (film): 3412, 2910, 1643, 1465, 1390, 1246, 822. All spectroscopic data are in accordance with literature. (Wille, G; Mayser, P; Thoma, W; Monsees, T; Baumgart, A; Schmitz, H. J.; Schrenk, D; Polborn, K; Steglich, W. *Bioorg. Med. Chem.* 2001, 9, 955.)



tert-butyl 2-((1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

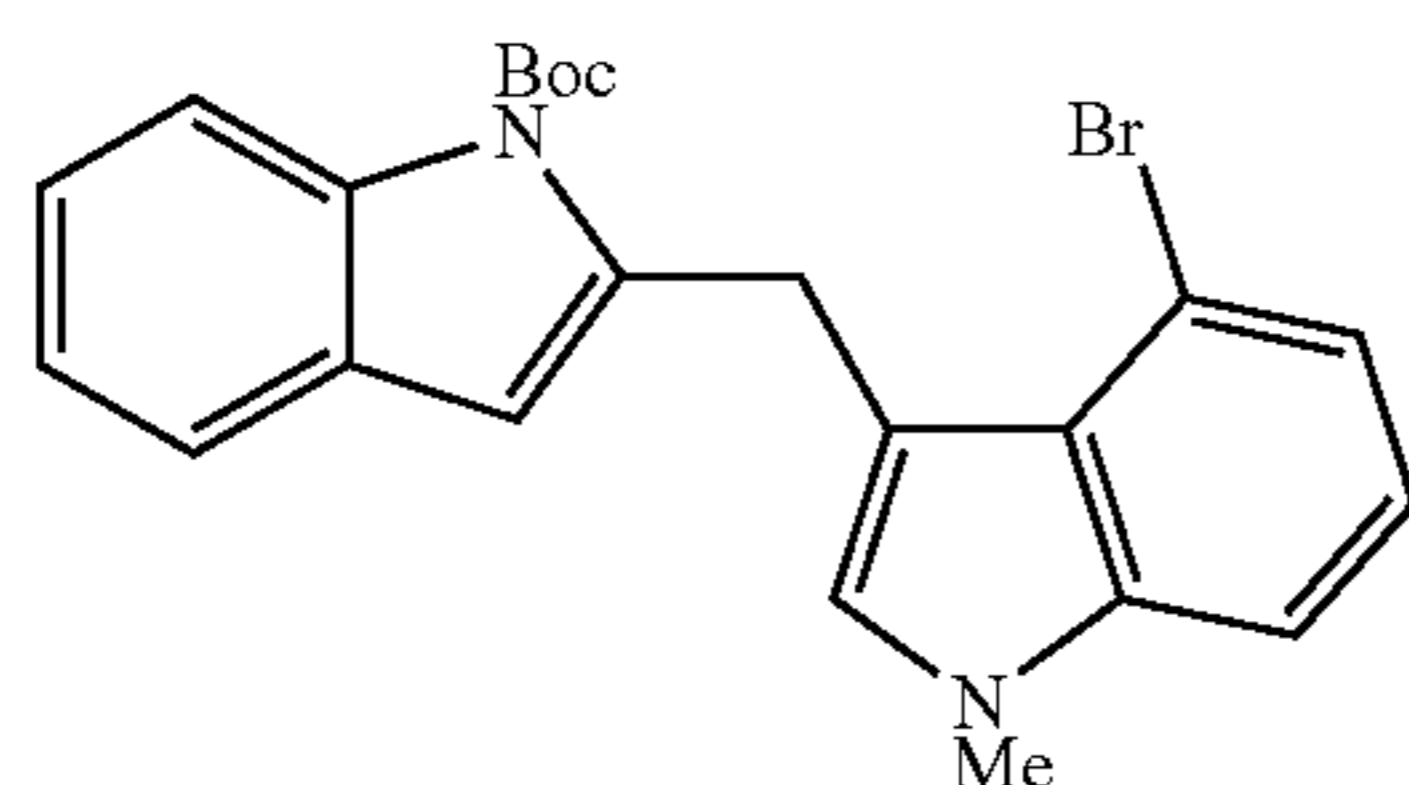
205 mg, 83% yield; brown solid, m.p.= $134-135^{\circ}\text{C}$ .  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ , TMS):  $\delta$  1.60 (s, 9H), 4.49 (s, 2H), 6.17 (s, 1H), 7.01 (d,  $J=2.4$  Hz, 1H), 7.09 (ddd,  $J=8.0$ , 6.8, 1.2 Hz, 1H), 7.14 (ddd,  $J=8.0$ , 6.8, 1.2 Hz, 1H), 7.21 (m, 2H), 7.33 (m, 1H), 7.39 (m, 1H), 7.56 (dd,  $J=8.4$ , 0.8 Hz, 1H), 8.00 (br, 1H), 8.11 (dd,  $J=8.4$ , 0.8 Hz, 1H).  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ ): 26.7, 28.3, 83.9, 108.7, 111.3, 113.8, 115.6, 119.4, 119.5, 120.0, 122.2, 122.7, 122.8, 123.4, 127.6, 129.4, 136.4, 137.0, 141.0, 150.9. IR (film):  $\nu$  3418, 2979, 1727, 1454, 1370, 1326, 1159, 1115, 1083, 906  $\text{cm}^{-1}$ . HRMS (ESI)  $m/z$  calcd. for  $\text{C}_{22}\text{H}_{22}\text{N}_2\text{O}_2$  ( $\text{M}+\text{Na}$ ) $^+$  369.1573, found 369.1580.

39



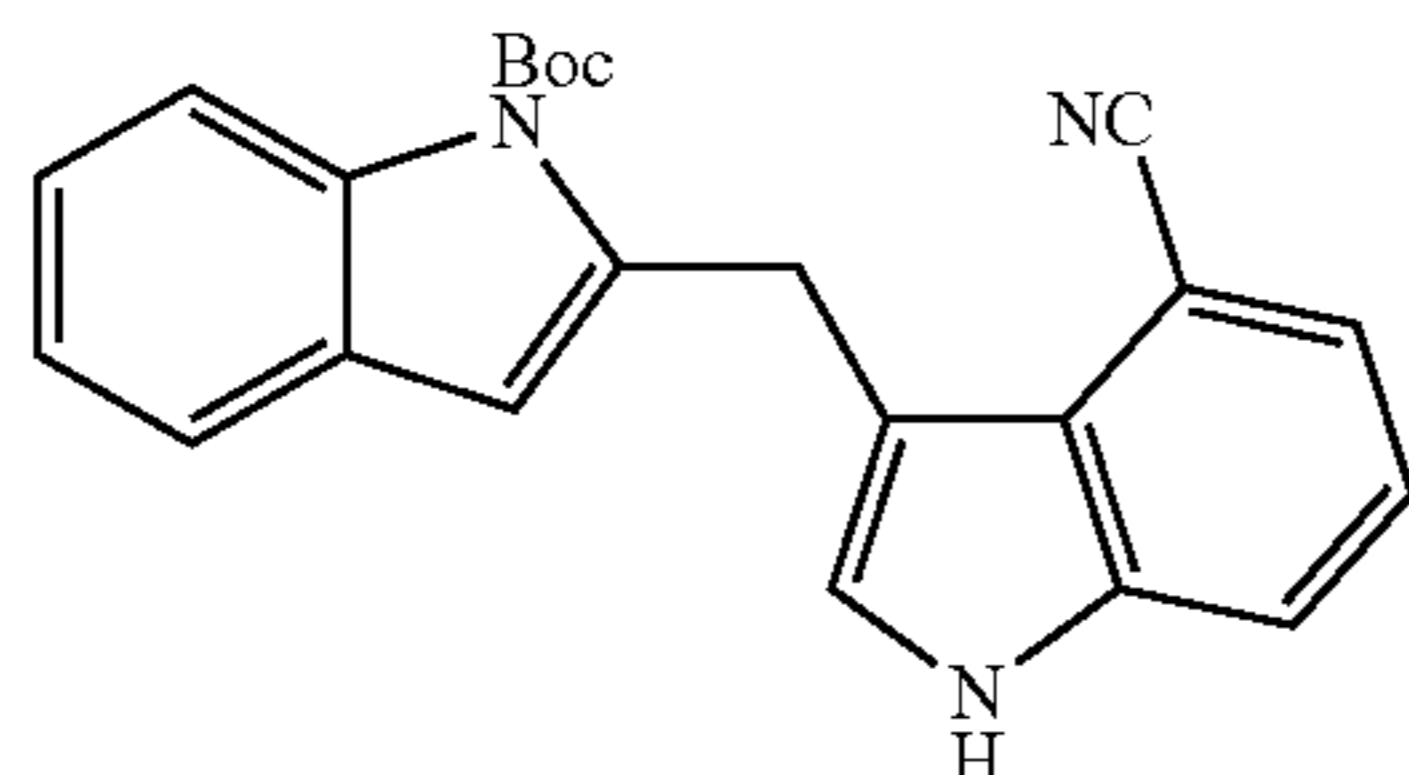
tert-butyl 2-((1-methyl-1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

49 mg, 88% yield; gray solid, m.p.=92-94° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 1.64 (s, 9H), 3.78 (s, 3H), 4.51 (s, 2H), 6.20 (s, 1H), 6.90 (s, 1H), 7.12 (ddd, J=8.0, 7.2, 0.8 Hz, 1H), 7.18 (td, J=8.0, 1.2 Hz, 1H), 7.26 (m, 2H), 7.36 (m, 2H), 7.58 (dt, J=8.0, 1.2 Hz, 1H), 8.16 (dd, J=8.0, 0.8 Hz, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 26.6, 28.3, 32.8, 83.8, 108.7, 109.3, 112.2, 115.6, 119.0, 119.5, 120.0, 121.7, 122.7, 123.4, 127.6, 128.0, 129.4, 137.0, 137.2, 141.3, 150.9. IR (film): ν 2976, 1727, 1453, 1369, 1324, 1156, 1114, 1081, 907 cm<sup>-1</sup>. HRMS (ESI) m/z calcd. for C<sub>23</sub>H<sub>25</sub>N<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 361.1911, found 361.1916.



tert-butyl 2-((4-bromo-1-methyl-1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

66 mg, 68% yield; brown solid, m.p.=161-162° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 1.61 (s, 9H), 3.76 (s, 3H), 4.79 (s, 2H), 6.19 (s, 1H), 6.79 (s, 1H), 7.11 (t, J=8.0 Hz, 1H), 7.23 (td, J=7.5, 1.0 Hz, 1H), 7.31 (m, 3H), 7.44 (d, J=7.0 Hz, 1H), 8.26 (dd, J=8.0, 1.0 Hz, 1H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): 150.9, 141.6, 138.5, 137.2, 129.5, 128.9, 125.9, 123.5, 123.4, 122.7, 122.6, 120.0, 115.6, 114.8, 113.8, 109.1, 108.7, 83.8, 33.0, 29.9, 28.2. IR (film): ν 2916, 1728, 1454, 1369, 1334, 1162, 1115, 1082, 908, 769, 736 cm<sup>-1</sup>. HRMS (ESI) m/z calcd. for C<sub>23</sub>H<sub>24</sub>BrN<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 439.1016, found 439.1016.

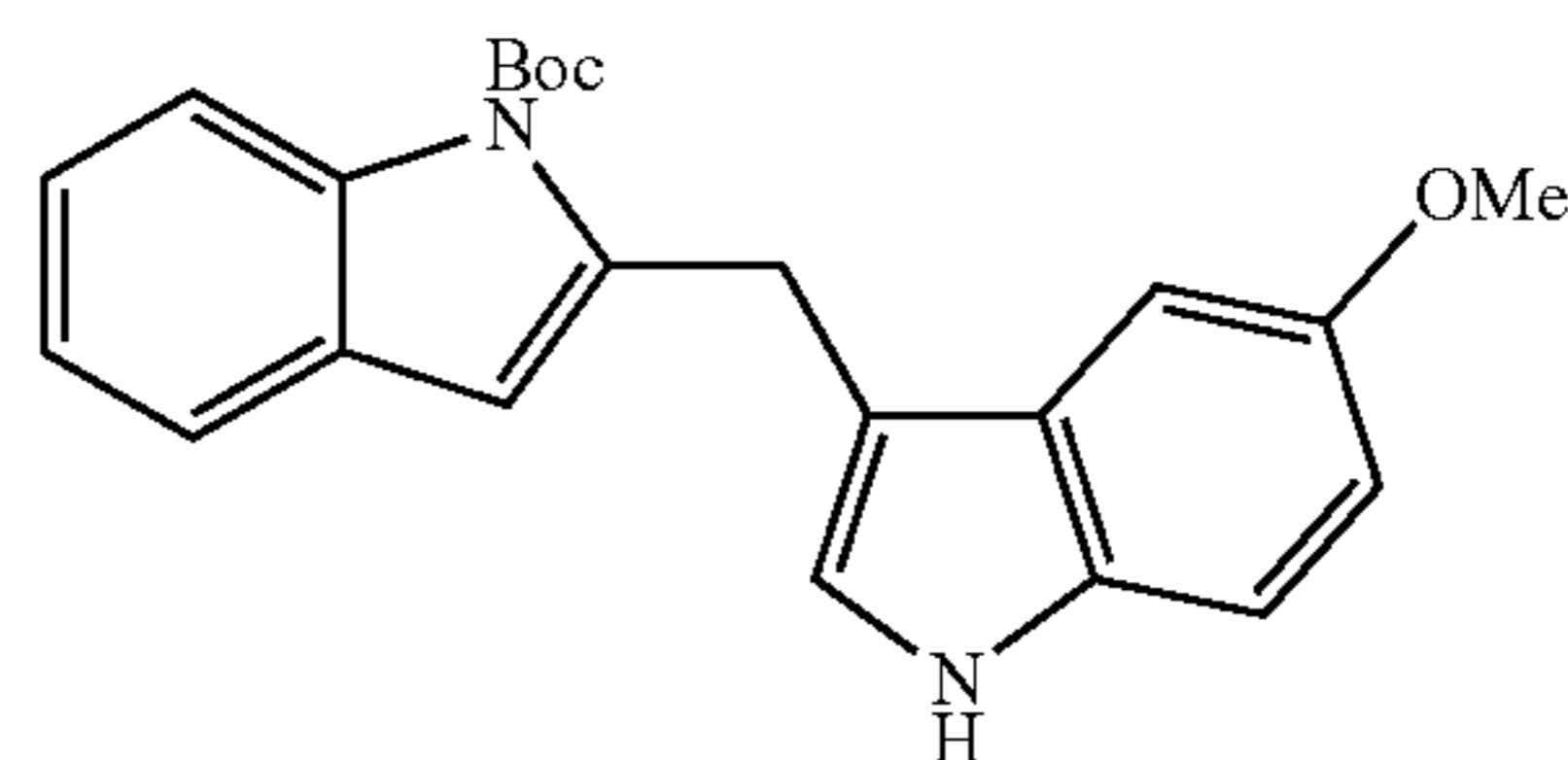


tert-butyl 2-((4-cyano-1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

62 mg, 81% yield; yellow solid, m.p.=155-157° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 1.52 (s, 9H), 4.75 (s, 2H),

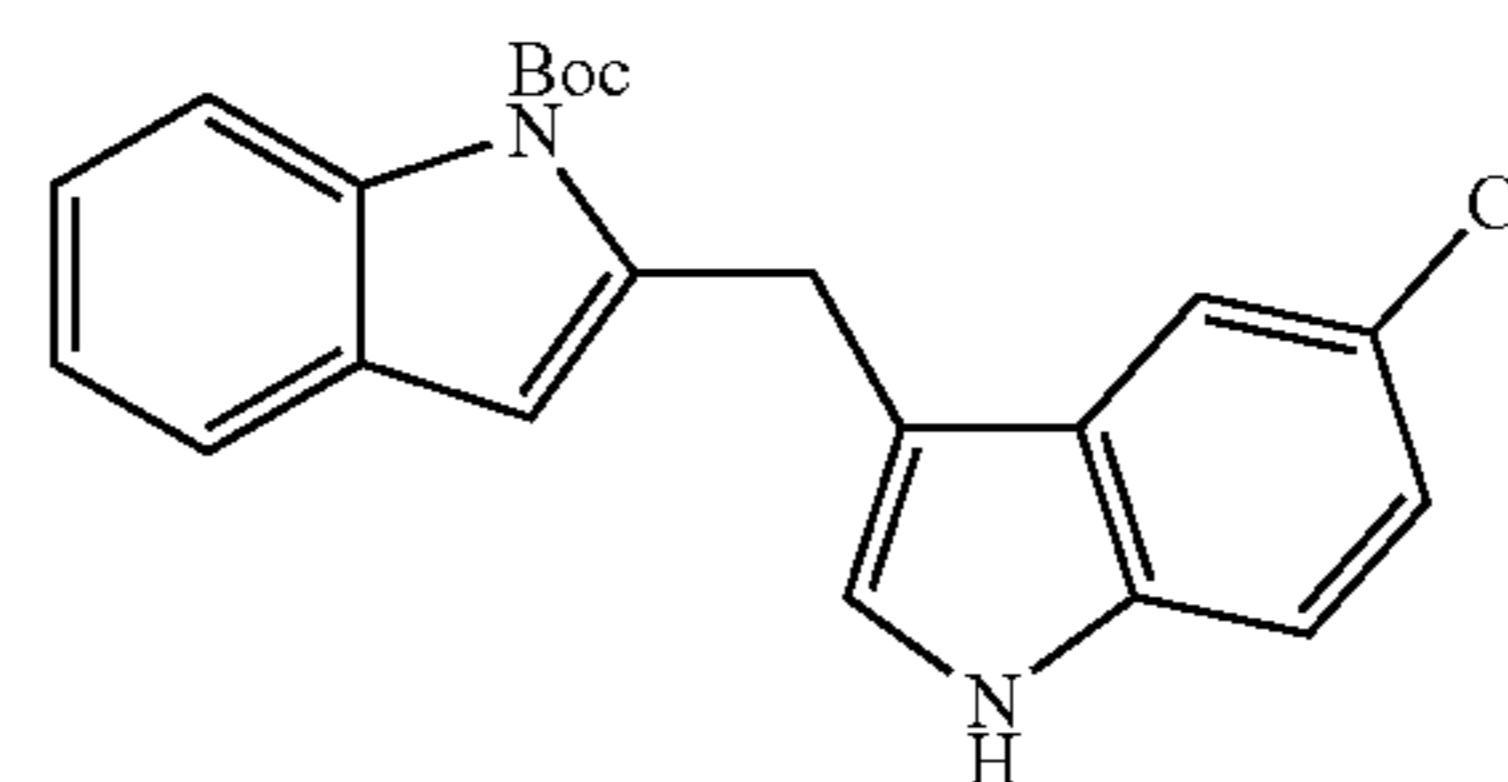
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6b 6.20 (s, 1H), 6.99 (s, 1H), 7.20 (m, 3H), 7.38 (dd, J=7.6, 0.4 Hz, 1H), 7.45 (dd, J=7.2, 0.8 Hz, 1H), 7.57 (dd, J=8.0, 0.8 Hz, 1H), 8.17 (d, J=8.0 Hz, 1H), 8.46 (br, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 150.8, 140.2, 137.2, 136.6, 129.3, 126.7, 126.4, 125.7, 123.6, 122.7, 121.8, 120.0, 119.3, 116.3, 115.7, 114.6, 109.0, 102.3, 83.9, 28.2, 26.5. IR (film): ν 3359, 2980, 2217, 1728, 1454, 1325, 1159, 1114, 1082, 907 cm<sup>-1</sup>. HRMS (ESI) m/z calcd. for C<sub>23</sub>H<sub>22</sub>N<sub>3</sub>O<sub>2</sub> (M+H)<sup>+</sup> 372.1707, found 372.1706.



tert-butyl 2-((5-methoxy-1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

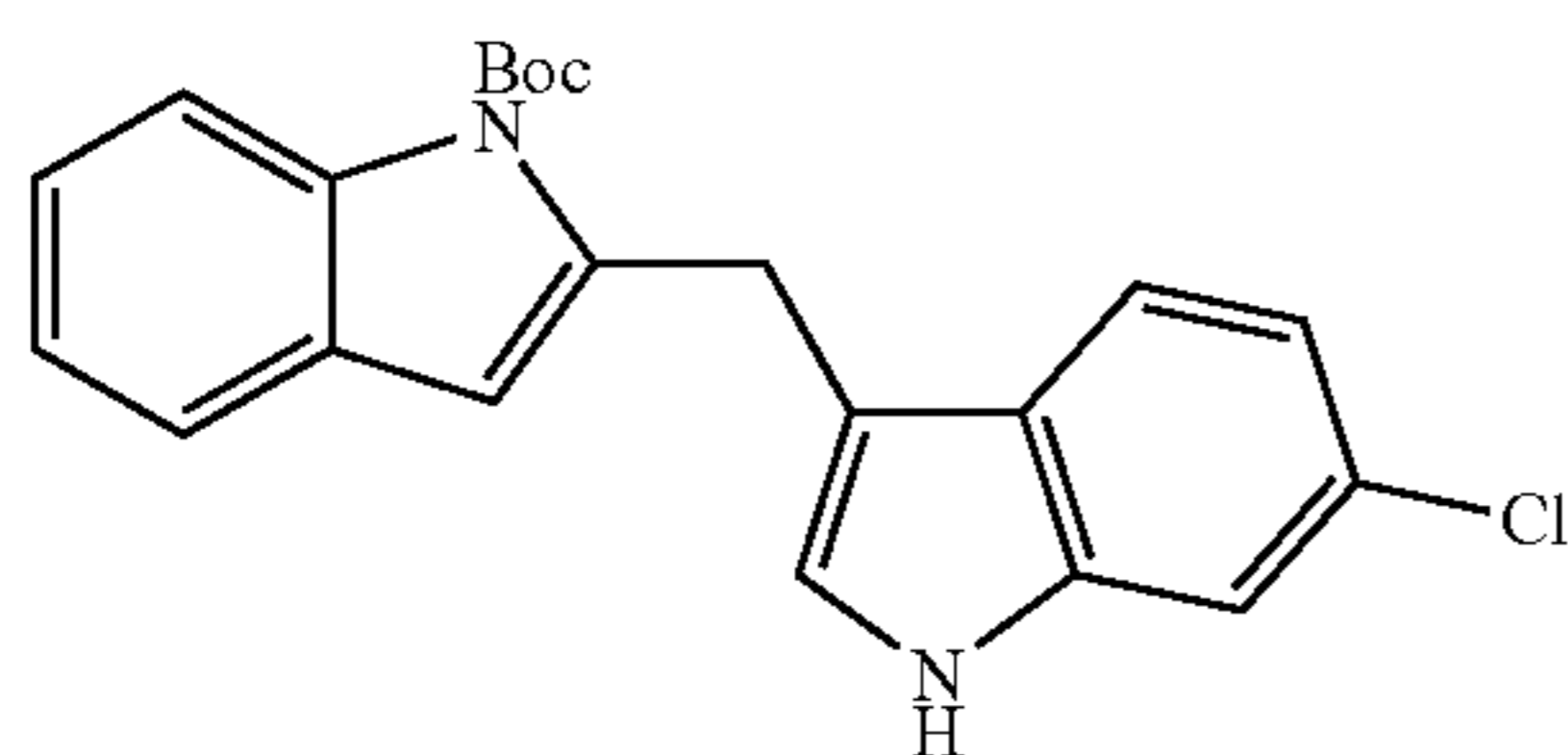
56 mg, 77% yield.; yellow solid, m.p.=98-99° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 1.60 (s, 9H), 3.86 (s, 3H), 4.51 (s, 2H), 6.23 (s, 1H), 6.94 (dd, J=8.5, 2.5 Hz, 1H), 7.03 (t, J=2.5 Hz, 2H), 7.22 (dd, J=8.0, 1.0 Hz, 1H), 7.30 (m, 1H), 7.33 (d, J=9.0 Hz, 1H), 7.41 (d, J=8.0 Hz, 1H), 7.98 (br, 1H), 8.20 (dd, J=8.0, 1.0 Hz, 1H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): 26.8, 28.3, 56.1, 83.9, 101.1, 108.7, 112.0, 112.5, 113.5, 115.6, 120.1, 122.7, 123.4, 123.6, 128.0, 129.4, 131.6, 137.0, 141.0, 150.9, 154.2. IR (film): ν 3418, 2979, 1727, 1485, 1453, 1369, 1326, 1215, 1160, 1115, 1082, 907 cm<sup>-1</sup>. HRMS (ESI) m/z calcd. for C<sub>23</sub>H<sub>25</sub>N<sub>2</sub>O<sub>3</sub> (M+H)<sup>+</sup> 377.1860, found 377.1855.



tert-butyl 2-((5-chloro-1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

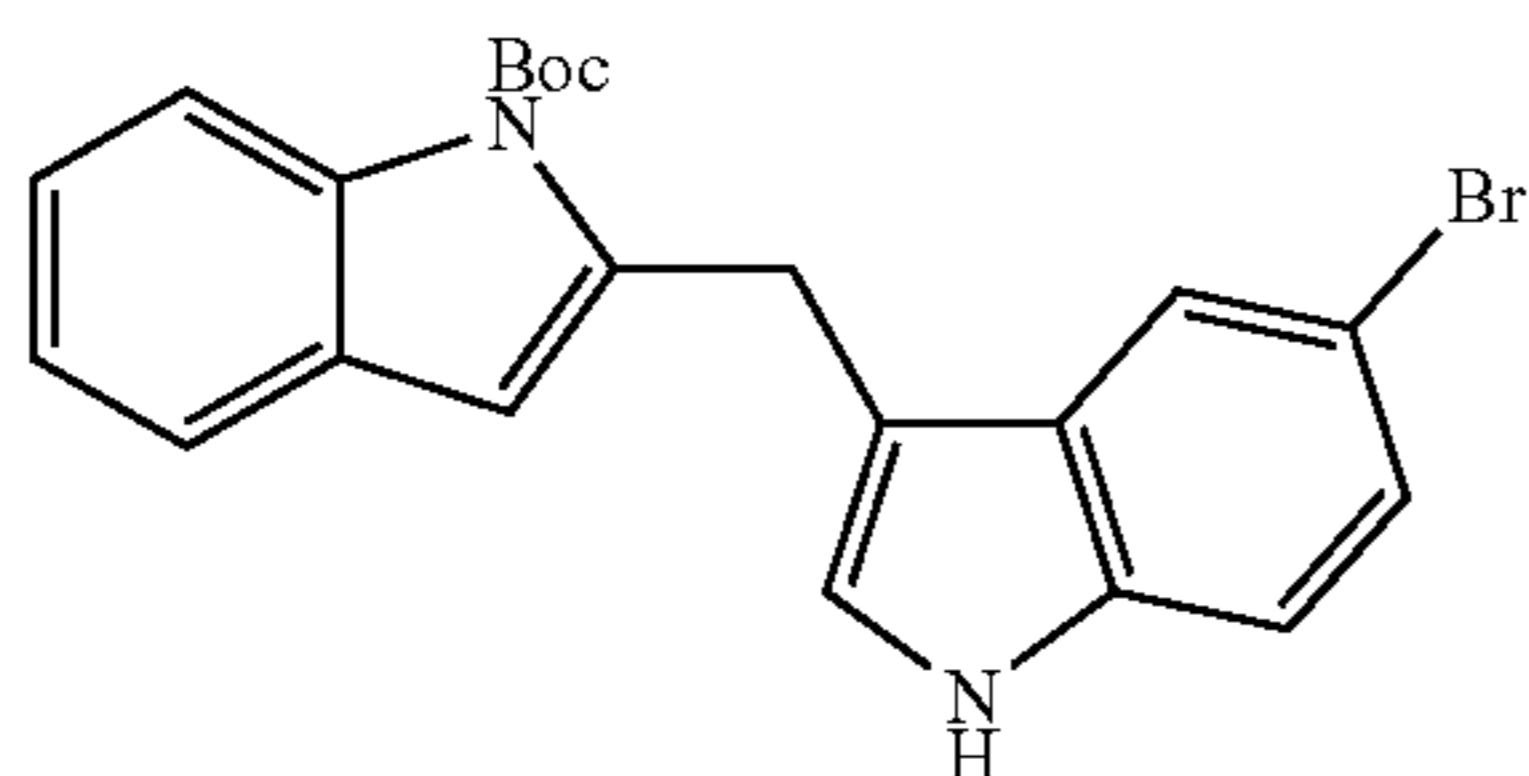
200 mg, 84% yield; yellow solid, m.p.=162-163° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 1.60 (s, 9H), 4.43 (s, 2H), 6.13 (s, 1H), 6.98 (d, J=2.4 Hz, 1H), 7.23 (m, 4H), 7.35 (d, J=7.6 Hz, 1H), 7.53 (d, J=2.0 Hz, 1H), 8.01 (br, 1H), 8.11 (dd, J=8.4, 0.8 Hz, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 150.9, 140.6, 137.0, 134.8, 129.3, 128.7, 125.4, 124.2, 123.6, 122.8, 122.5, 120.1, 118.8, 115.6, 113.7, 112.3, 108.7, 84.0, 28.3, 26.5. IR (film): 3416, 2981, 1728, 1707, 1453, 1368, 1327, 1220, 1157, 1115, 1080, 797, 746. HRMS (ESI) m/z calcd. for C<sub>22</sub>H<sub>22</sub>ClN<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 381.1365, found 381.1348.

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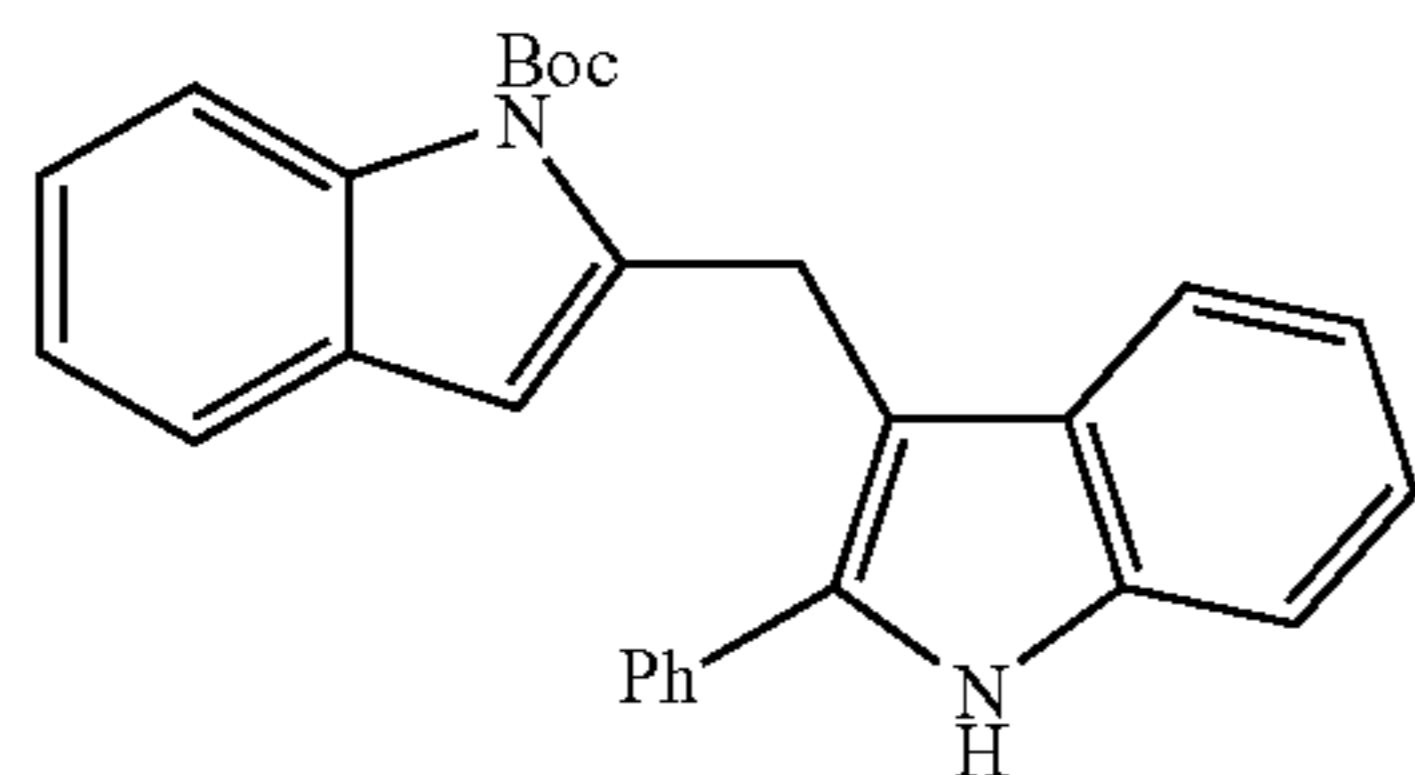
tert-butyl 2-((6-chloro-1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

65 mg, 85% yield; white solid, m.p.=155-156° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 1.61 (s, 9H), 4.47 (s, 2H), 6.16 (s, 1H), 6.95 (m, 1H), 7.08 (m, 1H), 7.18 (m, 1H), 7.25 (m, 1H), 7.35 (m, 2H), 7.46 (m, 1H), 7.98 (br, 1H), 8.13 (m, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 150.9, 140.6, 137.0, 136.8, 129.3, 128.1, 126.2, 123.6, 123.4, 122.8, 120.39, 120.33, 120.1, 115.6, 114.1, 111.2, 108.7, 84.0, 28.3, 26.6. IR (film): ν 3427, 2977, 1728, 1453, 1393, 1325, 1157, 1115, 1063, 905, 803 cm<sup>-1</sup>. HRMS (ESI) m/z calcd. for C<sub>22</sub>H<sub>22</sub>ClN<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 381.1365, found 381.1360.



tert-butyl 2-((5-bromo-1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

70 mg, 82% yield; brown solid, m.p.=159-160° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 1.62 (s, 9H), 4.34 (s, 2H), 6.04 (s, 1H), 6.86 (s, 1H), 7.07 (t, J=7.5 Hz, 1H), 7.15 (m, 3H), 7.27 (d, J=7.5 Hz, 1H), 7.60 (d, J=2.0 Hz, 1H), 7.96 (br, 1H), 8.07 (dd, J=8.0, 1.5 Hz, 1H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): 150.9, 140.6, 137.0, 135.0, 129.38, 129.32, 125.1, 124.1, 123.6, 122.8, 121.9, 120.1, 115.6, 113.5, 112.9, 112.8, 108.7, 84.0, 28.3, 26.5. IR (film): 3421, 2980, 1728, 1454, 1369, 1327, 1156, 1115, 1084, 907, 795. HRMS (ESI) m/z calcd. for C<sub>22</sub>H<sub>22</sub>BrN<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 425.0860, found 425.0860.

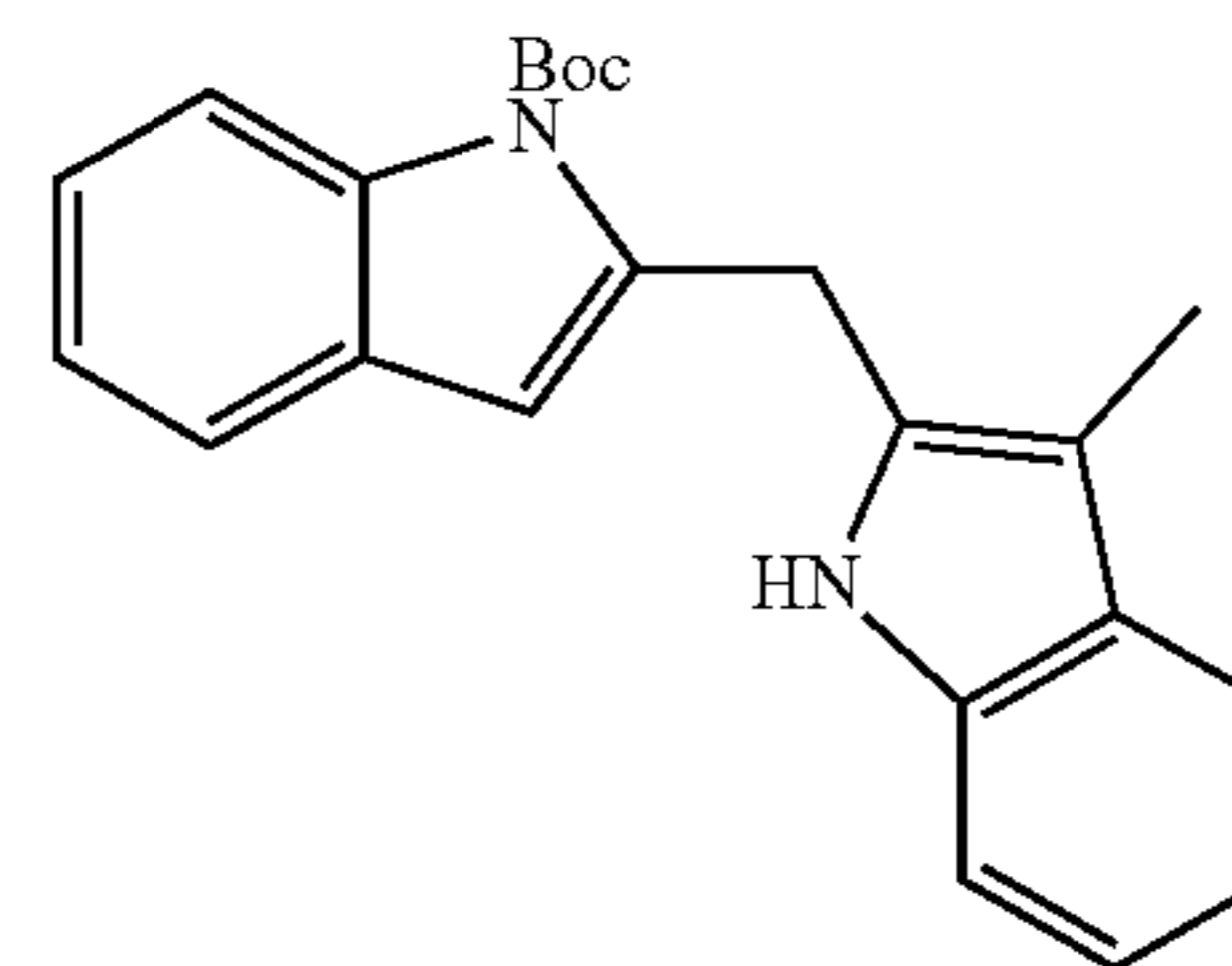


tert-butyl 2-((2-phenyl-1H-indol-3-yl)methyl)-1H-indole-1-carboxylate

270 mg, 80% yield; white solid, m.p.=145-146° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 1.68 (s, 9H), 4.55 (s, 2H),

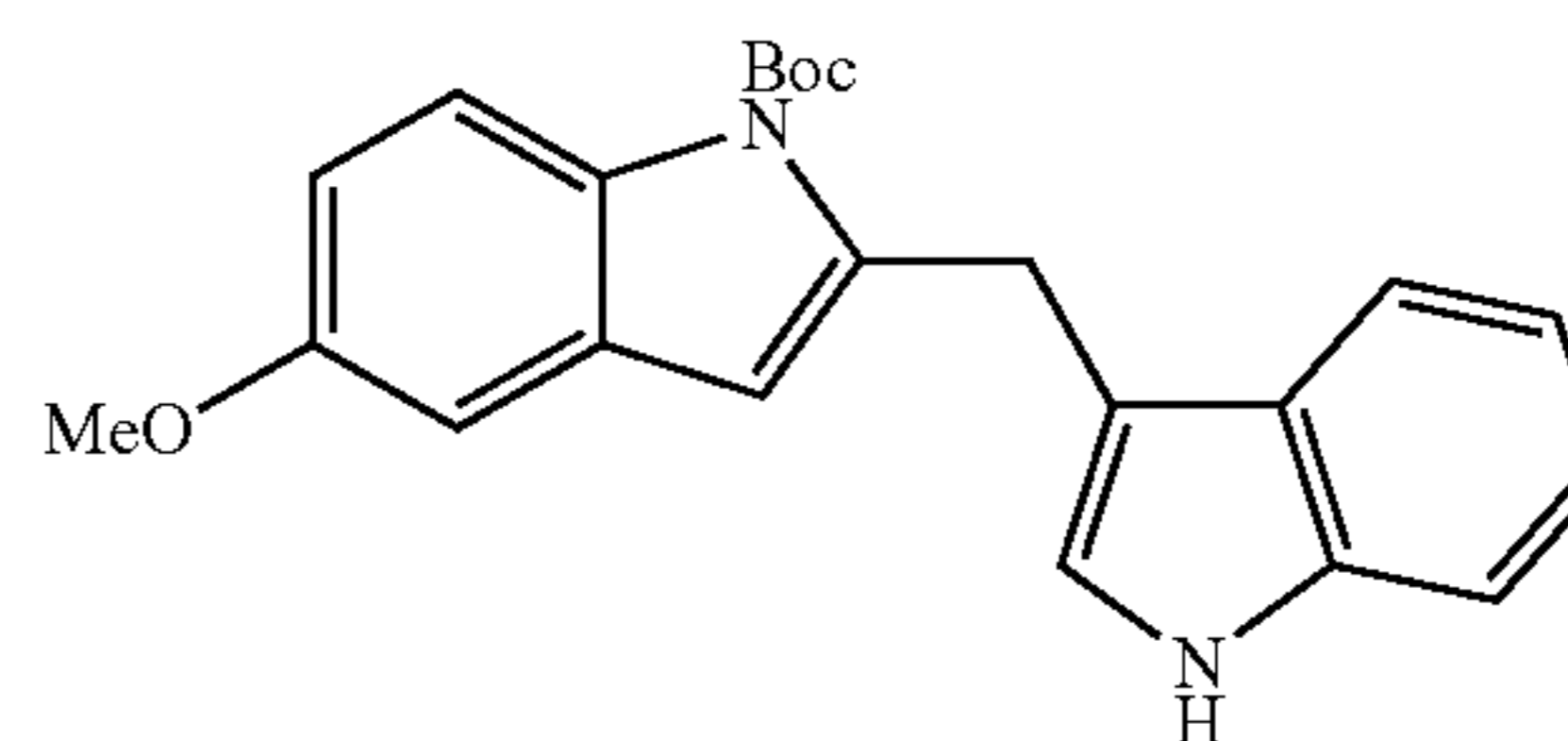
42

6g 6.05 (s, 1H), 7.11 (m, 2H), 7.21-7.41 (m, 7H), 7.49 (m, 3H), 8.14 (br, 2H), 8.17 (dd, J=8.4, 0.8 Hz, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 26.6, 28.5, 84.1, 108.9, 109.7, 111.0, 115.7, 119.6, 120.0, 120.1, 122.6, 122.7, 123.4, 127.7, 128.0, 129.1, 129.5, 132.7, 135.8, 136.1, 137.1, 141.6, 151.1. IR (film): ν 3412, 2997, 2974, 1730, 1454, 1369, 1326, 1248, 1161, 1114, 1082, 908, 737, 698 cm<sup>-1</sup>. HRMS (ESI) m/z calcd. for C<sub>28</sub>H<sub>27</sub>N<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 423.2068, found 423.2059.



tert-butyl 2-((3-methyl-1H-indol-2-yl)methyl)-1H-indole-1-carboxylate

6h 105 mg, 60% yield; brown solid, m.p.=144-145° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 1.76 (s, 9H), 2.37 (s, 3H), 4.56 (s, 2H), 6.31 (s, 1H), 7.15 (td, J=7.5, 1.0 Hz, 1H), 7.19 (td, J=7.0, 1.5 Hz, 1H), 7.23 (td, J=7.5, 1.0 Hz, 1H), 7.29 (m, 2H), 7.46 (dd, J=7.5, 1.0 Hz, 1H), 7.58 (d, J=8.0 Hz, 1H), 8.08 (dd, J=8.0, 1.0 Hz, 1H), 8.23 (br, 1H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): 151.2, 138.9, 136.6, 135.3, 131.7, 129.3, 129.3, 123.8, 123.0, 121.5, 120.2, 119.1, 118.5, 115.8, 110.6, 109.2, 108.4, 84.6, 28.4, 27.3, 8.7. IR (film): 3418, 2980, 1732, 1454, 1371, 1330, 1163, 1117, 1083, 909. HRMS (ESI) m/z calcd. for C<sub>23</sub>H<sub>25</sub>N<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 361.1911, found 361.1901.

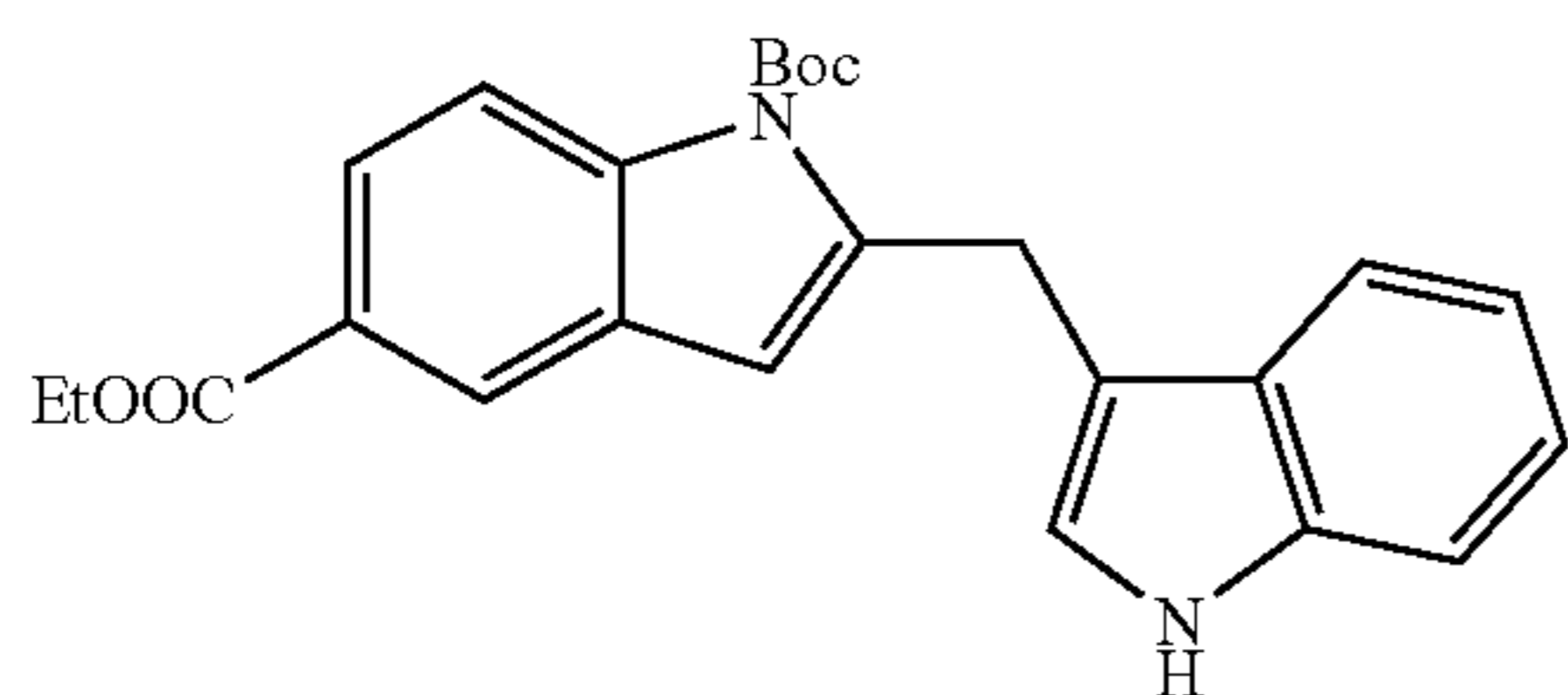


tert-butyl 2-((1H-indol-3-yl)methyl)-5-methoxy-1H-indole-1-carboxylate

6i 58 mg, 77% yield; yellow solid, m.p.=97-98° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 1.62 (s, 9H), 3.80 (s, 3H), 4.48 (s, 2H), 6.10 (s, 1H), 6.83 (d, J=2.8 Hz, 1H), 6.85 (dd, J=9.2, 2.8 Hz, 1H), 7.00 (d, J=2.4 Hz, 1H), 7.11 (ddd, J=8.0, 7.2, 0.8 Hz, 1H), 7.22 (ddd, J=8.0, 7.2, 1.2 Hz, 1H), 7.39 (dt, J=8.4, 0.8 Hz, 1H), 7.57 (d, J=7.6 Hz, 1H), 8.11 (br, 1H), 8.02 (d, J=8.8 Hz, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 155.9, 150.8, 141.8, 136.4, 131.7, 130.2, 127.6, 122.8, 122.2, 119.5, 119.4, 116.4, 113.8, 111.9, 111.3, 108.6, 102.8, 83.7, 55.8, 28.3, 26.8. IR (film): 3414, 2979, 1727, 1477, 1450, 1370, 1162, 1122, 1084, 908, 734. HRMS (ESI) m/z calcd. for C<sub>23</sub>H<sub>24</sub>N<sub>2</sub>O<sub>3</sub>Na(M+Na) 399.1680, found 399.1666.

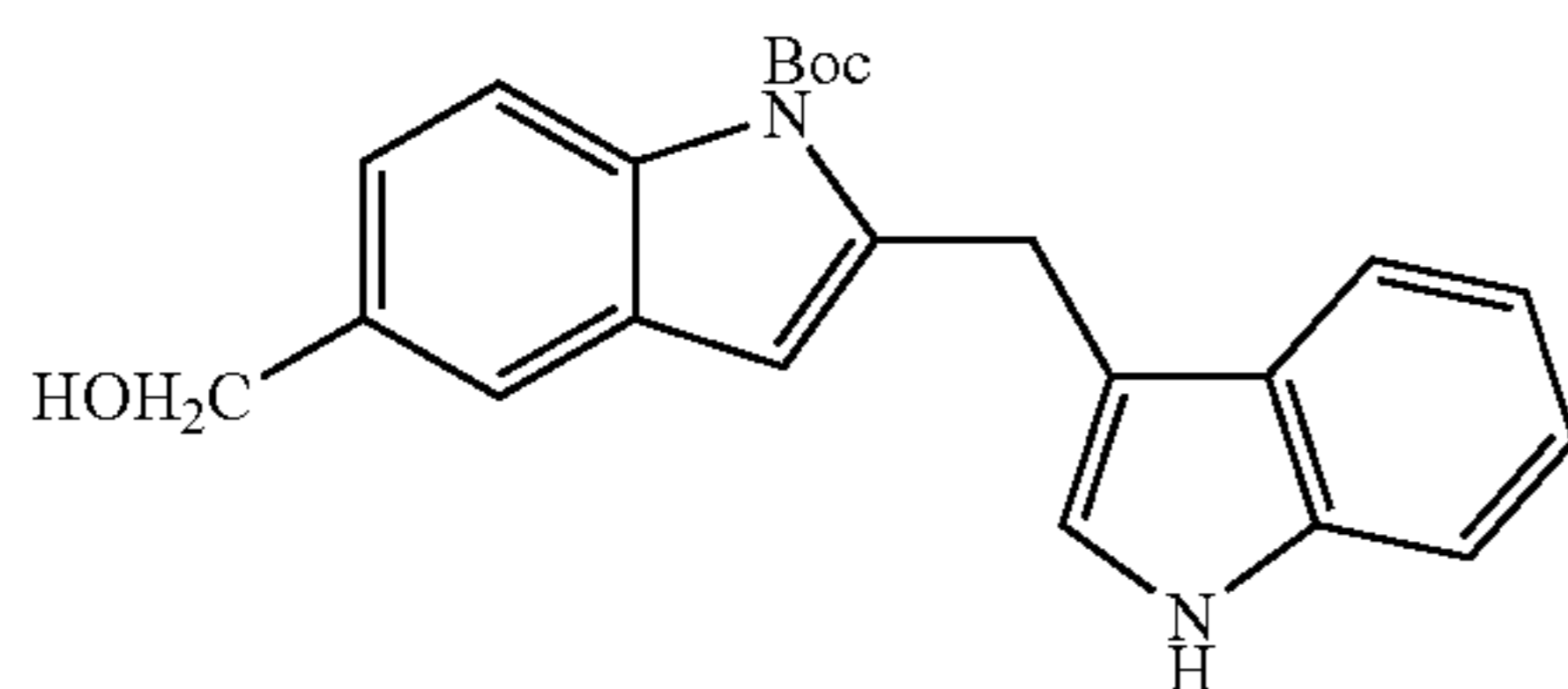


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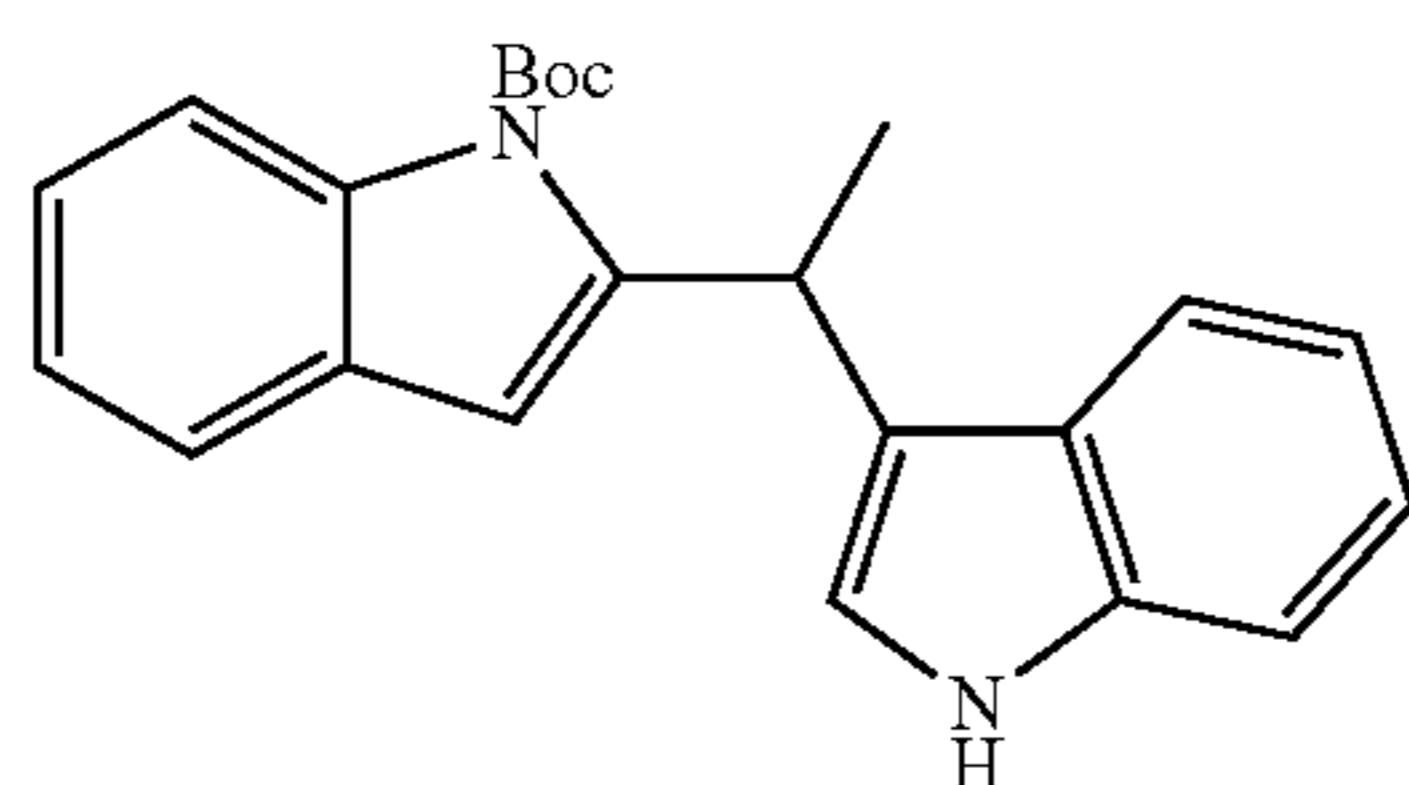
2-(1H-Indol-3-ylmethyl)-indole-1,5-dicarboxylic acid 1-tert-butyl ester 5-ethyl ester

49 mg, 62% yield; green solid, m.p.=100-102° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 1.38 (t, J=7.08 Hz, 3H), 1.6 (s, 9H), 4.36 (q, J=7.16 Hz, 2H), 4.48 (s, 2H), 6.25 (s, 1H), 6.99 (d, J=2.32, 1H), 7.09 (ddd, J=8.00, 7.09, 1.00 Hz, 1H), 7.22 (ddd, J=8.16, 7.00, 1.2 Hz, 1H) 7.38 (d, J=8.2, 1H), 7.54 (d, J=7.92 Hz, 1H), 7.94 (dd, J=8.84, 1.80 Hz, 1H) 8.08 (d, J=1.6 Hz, 2H), 8.15 (d, J=8.84 Hz, 1H); <sup>13</sup>C NMR (CDCl<sub>3</sub>, 100 MHz): δ 14.61, 26.81, 28.33, 60.94, 84.67, 109.09, 111.42, 113.47, 115.26, 119.36, 119.71, 122.24, 122.36, 122.90, 124.88, 125.01, 127.53, 129.13, 136.55, 139.80, 142.50, 150.62, 161.39. IR (film) 730.94, 906.99, 1086.17, 1159.77, 1242.33, 1370.15, 1709.71 ν cm<sup>-1</sup>. HRMS (ESI) m/z calcd for C<sub>25</sub>H<sub>26</sub>N<sub>2</sub>O<sub>4</sub> (M+H)<sup>+</sup> 419.1966, found 419.1980.



5-Hydroxymethyl-2-(1H-indol-3-ylmethyl)-indole-1-carboxylic acid tert-butyl ester

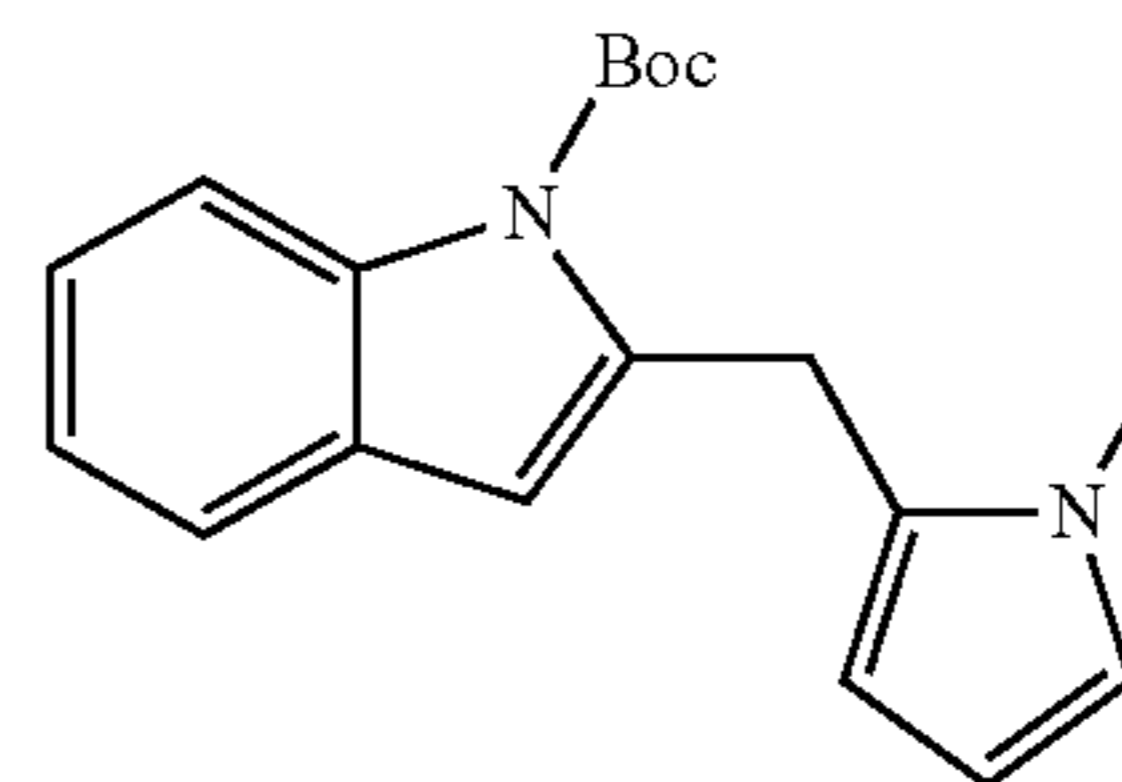
25 mg, 55% yield; brown oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 1.59 (s, 9H), 4.46 (s, 2H), 4.69 (s, 2H), 6.14 (s, 1H), 6.94 (d, J=2.40 Hz, 1H), 7.08 (ddd, J=7.96, 7.00, 1.04 Hz, 1H), 7.17-7.23 (m, 2H) 7.38 (d, J=1.04, 1H), 7.36 (dt, J=8.16, 1.00 Hz, 1H), 7.56 (dq, J=7.92, 1.00 Hz, 1H) 8.03 (s, 1H), 8.09 (d, J=9.64 Hz, 1H); <sup>13</sup>C NMR (CDCl<sub>3</sub>, 100 MHz): δ 26.82, 28.38, 65.92, 84.13, 108.77, 111.38, 113.79, 115.78, 118.80, 119.44, 119.63, 122.27, 122.88, 122.9, 127.61, 129.64, 135.47, 136.54, 136.70, 141.67, 150.90. IR (film) 731.67, 908.08, 1032.86, 1252.46, 1315.52, 1726.58 ν cm<sup>-1</sup>. HRMS (ESI) m/z calcd for C<sub>23</sub>H<sub>24</sub>N<sub>2</sub>O<sub>3</sub> (M+H)<sup>+</sup> 377.1860, found 377.1863.



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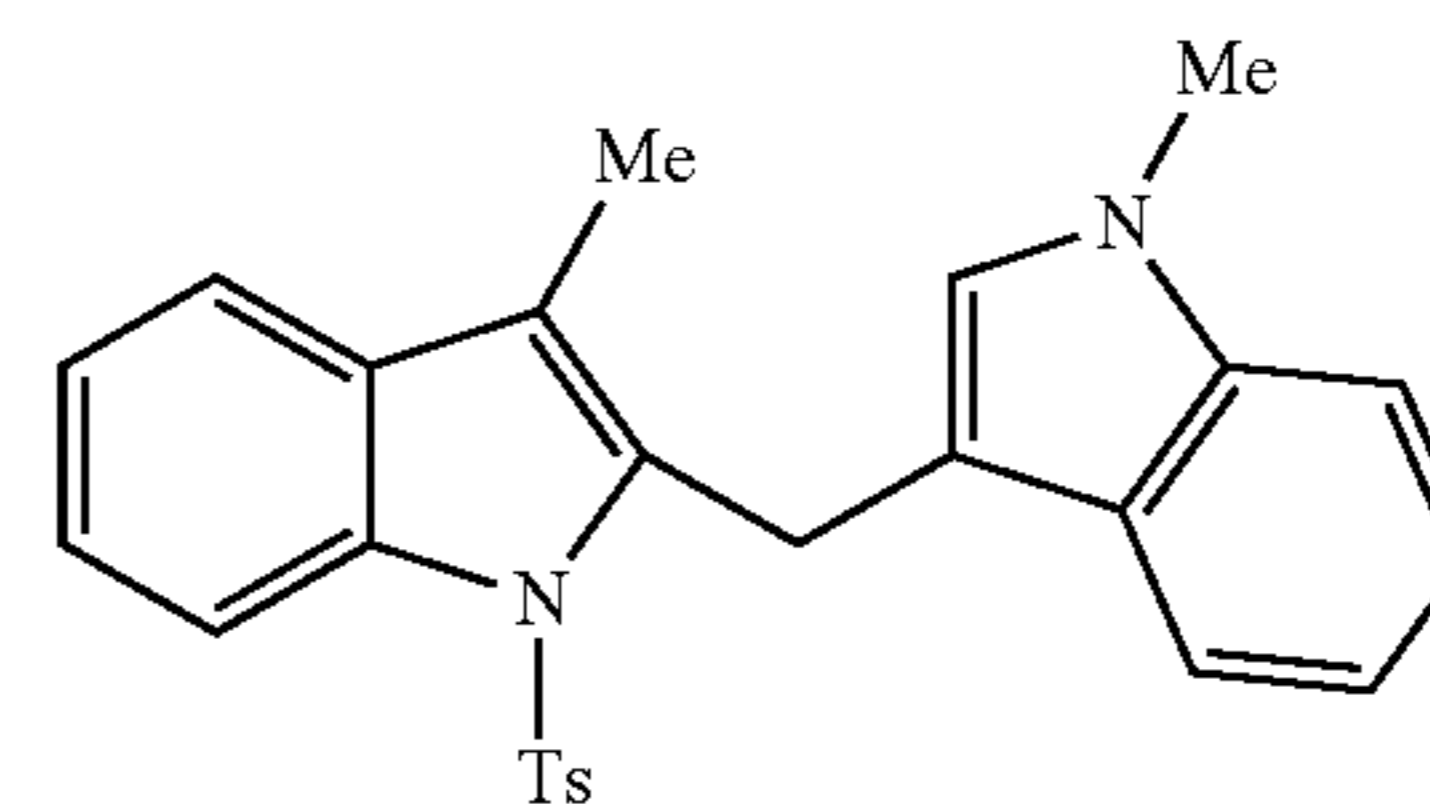
tert-butyl 2-(1-(1H-indol-3-yl)ethyl)-1H-indole-1-carboxylate

25 mg, 70% yield, brown solid, m.p.=141-142° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 1.47 (s, 9H), 1.75 (d, J=7.2 Hz, 3H), 5.19 (q, J=7.2 Hz, 1H), 6.35 (s, 1H), 6.78 (dd, J=2.4, 0.8 Hz, 1H), 7.07 (ddd, J=8.0, 6.7, 0.8 Hz, 1H), 7.17 (m, 2H), 7.23 (ddd, J=8.8, 6.8, 1.6 Hz, 1H), 7.34 (dt, J=8.0, 0.8 Hz, 1H), 7.40 (ddd, J=7.6, 1.6, 0.8 Hz, 1H), 7.56 (d, J=8.0 Hz, 1H), 7.90 (br, 1H), 8.10 (dd, J=8.4, 0.8 Hz, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 150.7, 146.0, 137.3, 136.7, 129.2, 126.8, 123.5, 122.6, 122.1, 121.3, 121.0, 120.2, 119.8, 119.4, 115.5, 111.3, 107.3, 83.8, 30.8, 28.1, 21.4. IR (film): ν 3421, 2976, 2362, 1728, 1454, 1368, 1326, 1156, 1116, 908 cm<sup>-1</sup>; HRMS (ESI) m/z calcd. for C<sub>23</sub>H<sub>24</sub>N<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 361.1911, found 361.1908.



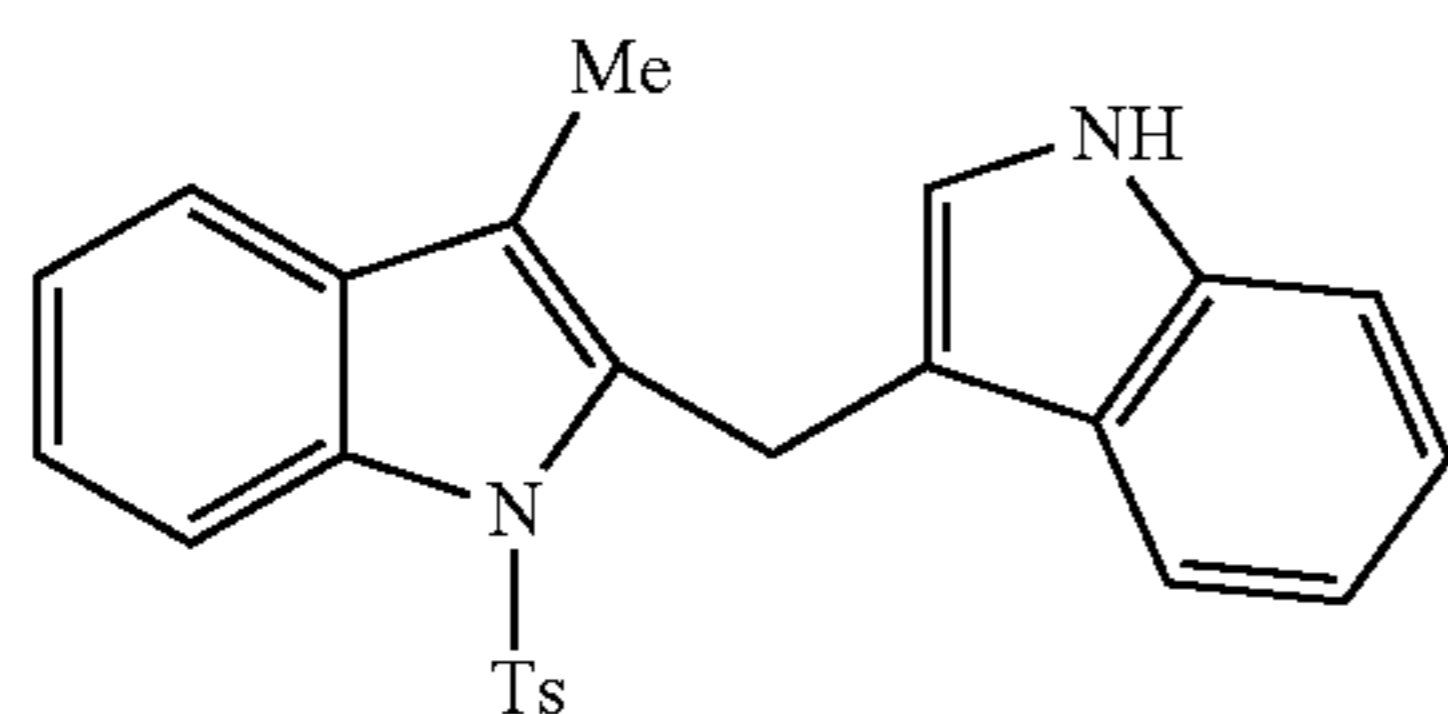
tert-butyl 2-((1-methyl-1H-pyrrol-2-yl)methyl)-1H-indole-1-carboxylate

21 mg, 68% yield; brown oil. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 1.66 (s, 9H), 3.52 (s, 3H), 4.29 (s, 2H), 5.92 (s, 1H), 5.98 (m, 1H), 6.12 (m, 1H), 6.64 (m, 1H), 7.22 (m, 2H), 7.35 (d, J=8.0 Hz, 1H), 8.11 (d, J=8.0 Hz, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 28.1, 28.4, 33.8, 84.1, 107.0, 108.2, 108.6, 115.7, 120.1, 121.8, 122.8, 123.6, 129.3, 129.7, 136.9, 140.1, 150.8. IR (film): ν 2976, 1729, 1454, 1369, 1161, 1081, 744 cm<sup>-1</sup>. HRMS (ESI) m/z calcd. for C<sub>19</sub>H<sub>22</sub>N<sub>2</sub>O<sub>2</sub> (M+Na)<sup>+</sup> 333.1573, found 333.1575.

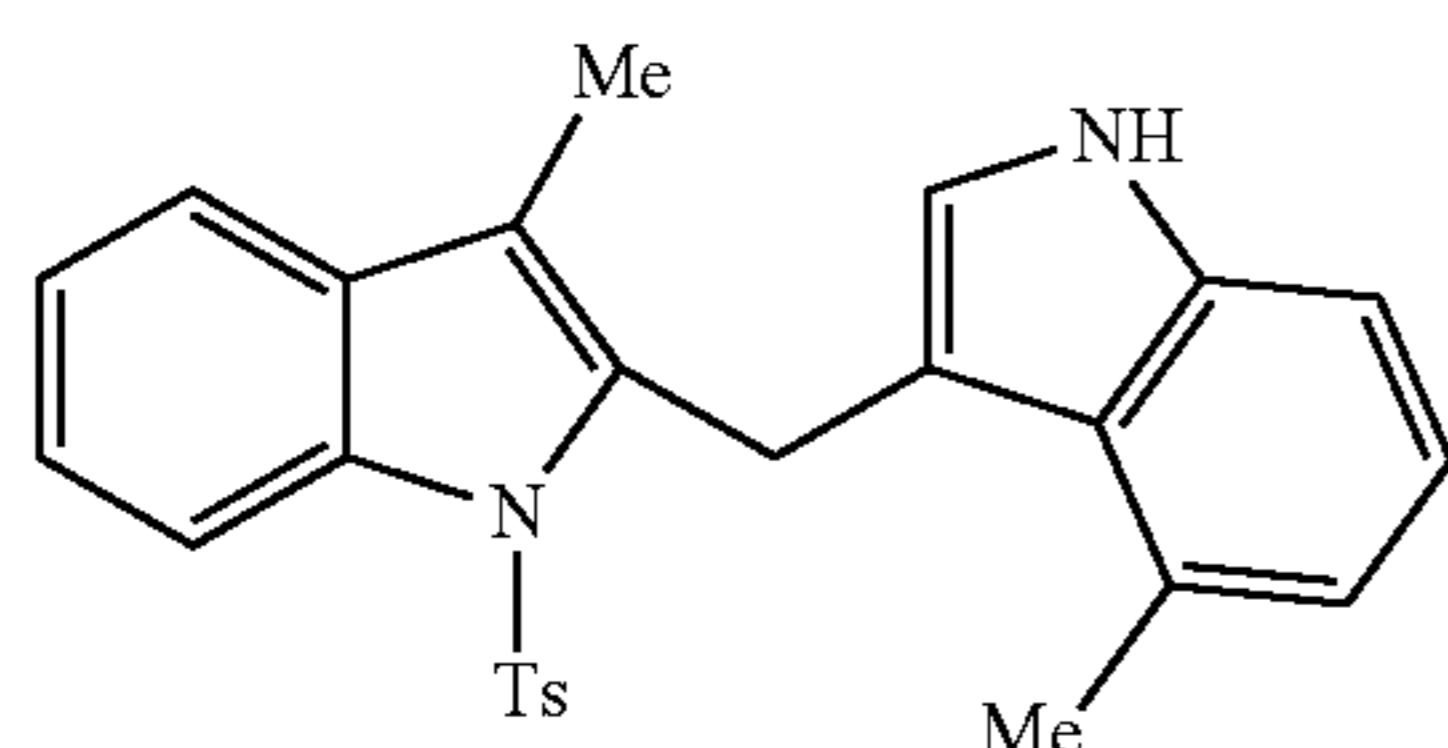


Compound 9a was isolated as brown oil (16 mg, 76%, [0.05 mmol]; 62 mg, 73% [0.2 mmol]). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 8.23 (d, J=5.0 Hz, 1H), 7.60 (d, J=10.0 Hz, 1H), 7.44 (d, J=10.0 Hz, 1H), 7.30-7.24 (m, 4H), 7.22-7.19 (m, 2H), 7.11-7.08 (m, 1H), 6.86 (d, J=10.0 Hz, 2H), 6.39 (s, 1H), 4.51 (s, 2H), 3.53 (s, 3H), 2.24 (s, 3H), 2.23 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 144.1, 137.1, 137.0, 136.5, 135.7, 131.4, 129.3, 127.74, 127.69, 126.5, 124.5, 123.5, 121.7, 119.2, 119.1, 118.8, 117.3, 115.4, 112.1, 109.2, 32.7, 22.1, 21.7, 9.5. IR (neat) ν 3681, 3639, 2928, 1652, 1537. HRMS (ESI) m/z calcd for C<sub>26</sub>H<sub>24</sub>N<sub>2</sub>O<sub>2</sub>S (M+Na)<sup>+</sup> 451.1451, found 451.1460.

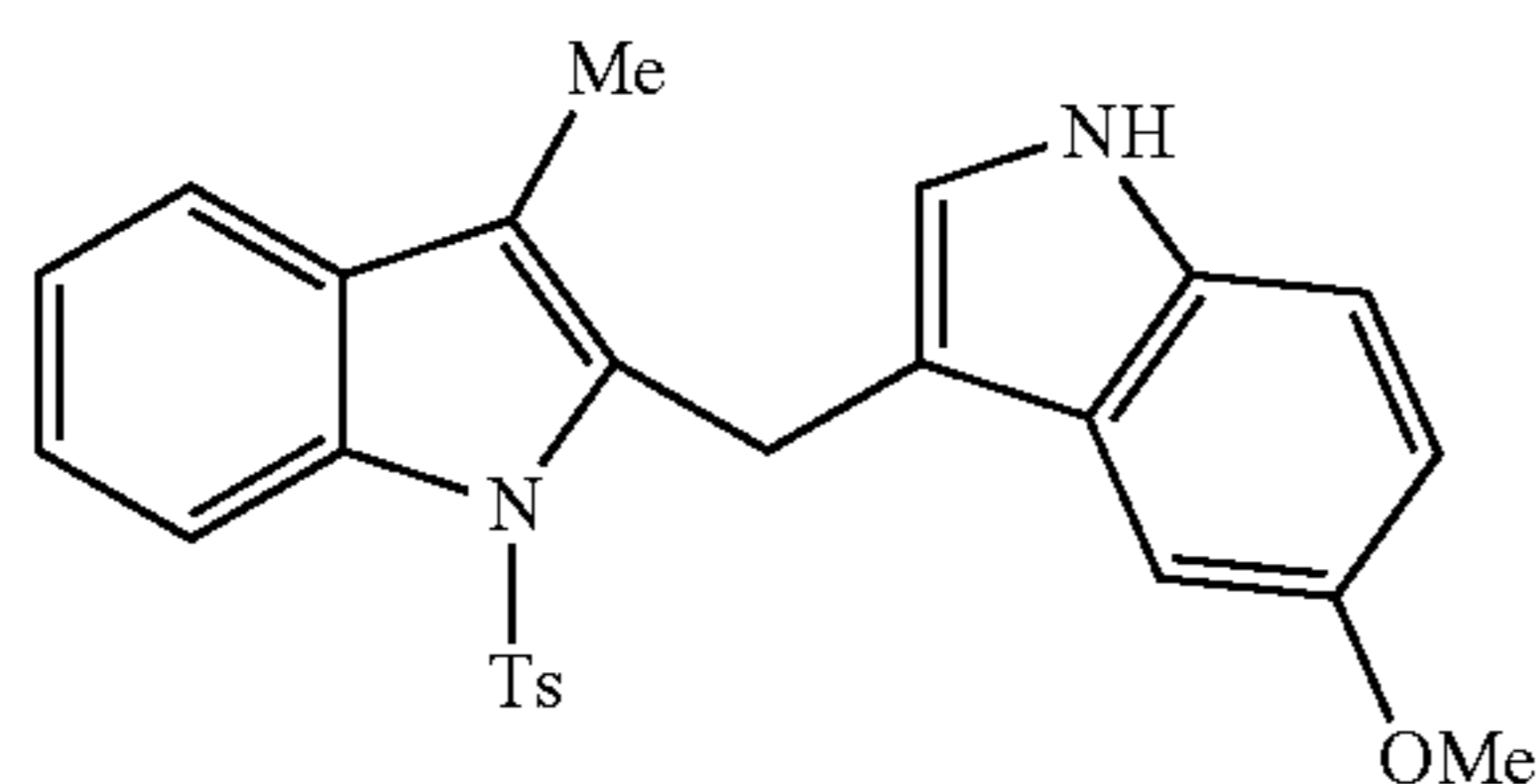
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Compound 9b was isolated as white solid (15 mg, 75%). mp=176-178° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 8.20 (d, J=10.0 Hz, 1H), 7.80 (s, 1H), 7.58 (d, J=10.0, 1H), 7.42 (d, J=5.0 Hz, 1H), 7.33 (d, J=10.0 Hz, 2H), 7.30-7.22 (m, 3H), 7.14 (t, J=10.0 Hz, 1H), 7.07 (t, J=10.0 Hz, 1H), 6.87 (d, J=5.0 Hz, 2H), 6.60 (s, 1H), 4.51 (s, 2H), 2.21 (s, 3H), 2.19 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ 144.2, 136.9, 136.4, 136.2, 135.5, 131.5, 129.4, 127.3, 126.5, 124.5, 123.5, 123.0, 122.1, 119.6, 119.0, 118.8, 117.6, 115.4, 113.7, 111.3, 22.3, 21.7, 9.5. IR (neat) ν 3676, 2948, 1734, 1692, 1660, 1530. HRMS (ESI) m/z calcd for C<sub>25</sub>H<sub>22</sub>N<sub>2</sub>O<sub>2</sub>S (M+Na)<sup>+</sup> 437.1294, found 437.1297. X-ray structure (CCDC 1016687).



Compound 9c was isolated as pink oil (33 mg, 77%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 8.28 (d, J=8.0 Hz, 1H), 7.64 (s, 1H), 7.46 (d, J=8.0 Hz, 1H), 7.40 (d, J=8.0 Hz, 2H), 7.36-7.26 (m, 2H), 7.14-7.13 (m, 1H), 7.06 (d, J=8.0 Hz, 1H), 6.93 (d, J=8.0 Hz, 2H), 6.88 (d, J=8.0 Hz, 1H), 6.13 (s, 1H), 4.78 (s, 2H), 2.84 (s, 3H), 2.24 (s, 3H), 2.15 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ 144.3, 137.1, 136.8, 136.5, 135.5, 131.4, 131.3, 129.5, 126.8, 126.0, 124.5, 123.4, 122.44, 122.38, 121.3, 118.7, 117.4, 115.3, 115.0, 109.2, 24.4, 21.8, 21.0, 9.1. IR (neat) ν 3361, 2925, 1717, 1685, 1647, 1521. HRMS (ESI) m/z calcd for C<sub>26</sub>H<sub>24</sub>N<sub>2</sub>O<sub>2</sub>S (M+Na)<sup>+</sup> 451.1451, found 451.1454.



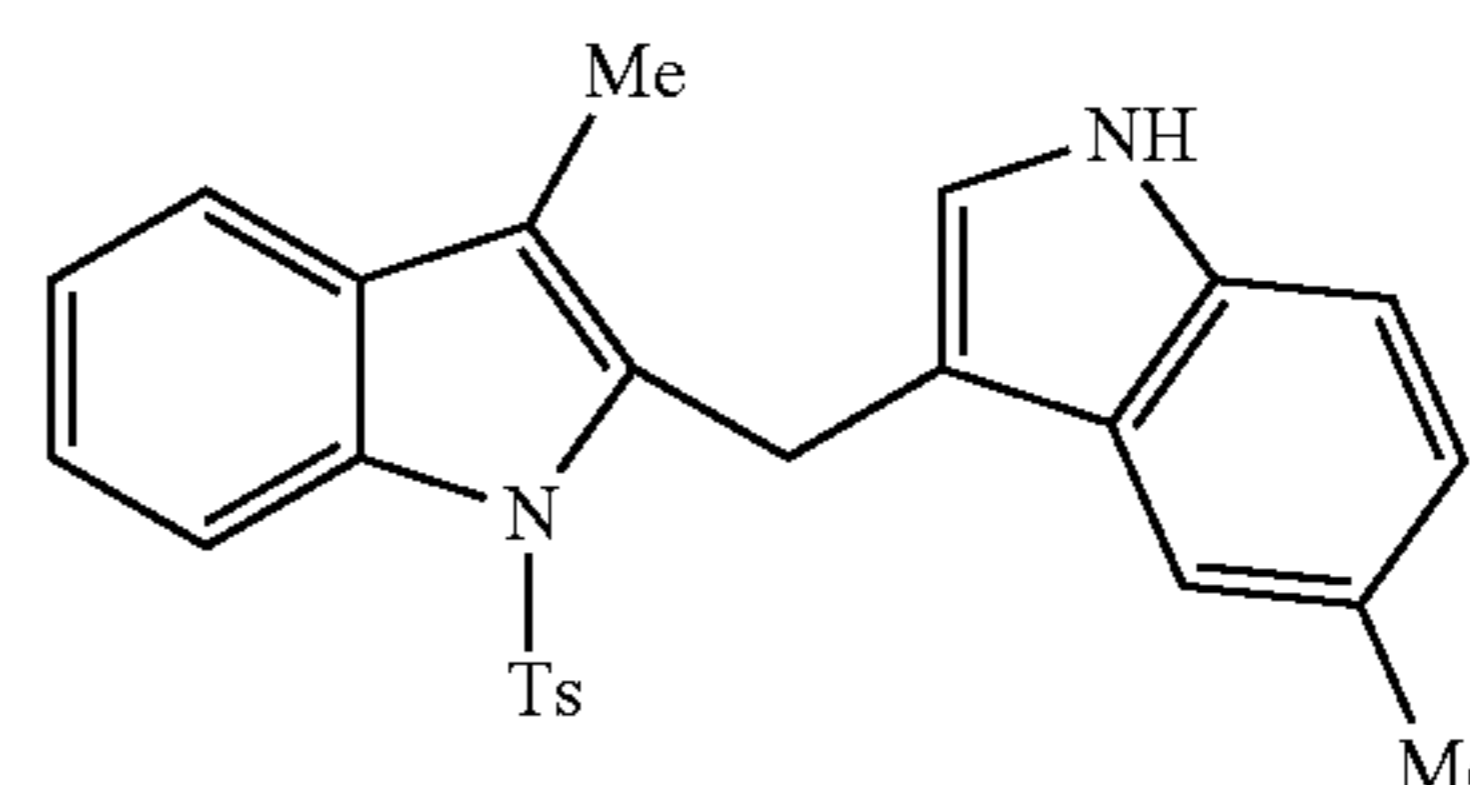
Compound 9d was isolated as yellow oil (21 mg, 95%). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 8.20 (d, J=5.0 Hz, 1H), 7.69 (s, 1H), 7.43 (d, J=10.0 Hz, 1H), 7.34 (d, J=5.0 Hz, 2H), 7.31-7.28 (m, 1H), 7.18 (d, J=5.0 Hz, 1H), 7.03 (d, J=2.5 Hz, 1H), 6.91 (d, J=10.0 Hz, 2H), 6.82 (dd, J=10.0, 2.5 Hz, 1H), 6.63 (s, 1H), 4.50 (s, 2H), 3.82 (s, 3H), 2.25 (s, 3H), 2.23 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ 154.3, 144.2, 136.9, 136.3, 135.5, 131.6, 131.5, 129.4, 127.7, 126.6, 124.5, 123.7, 123.5, 118.7, 117.6, 115.4, 113.6, 112.4, 111.9, 101.0, 56.1, 22.4, 21.7, 9.5. IR (neat) ν 3662, 3447, 2943,

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1717, 1652, 1537, 1521. HRMS (ESI) m/z calcd for C<sub>26</sub>H<sub>24</sub>N<sub>2</sub>O<sub>3</sub>S (M+Na)<sup>+</sup> 467.1400, found 467.1403.

9b

5



9e

10

15

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25

9c

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35

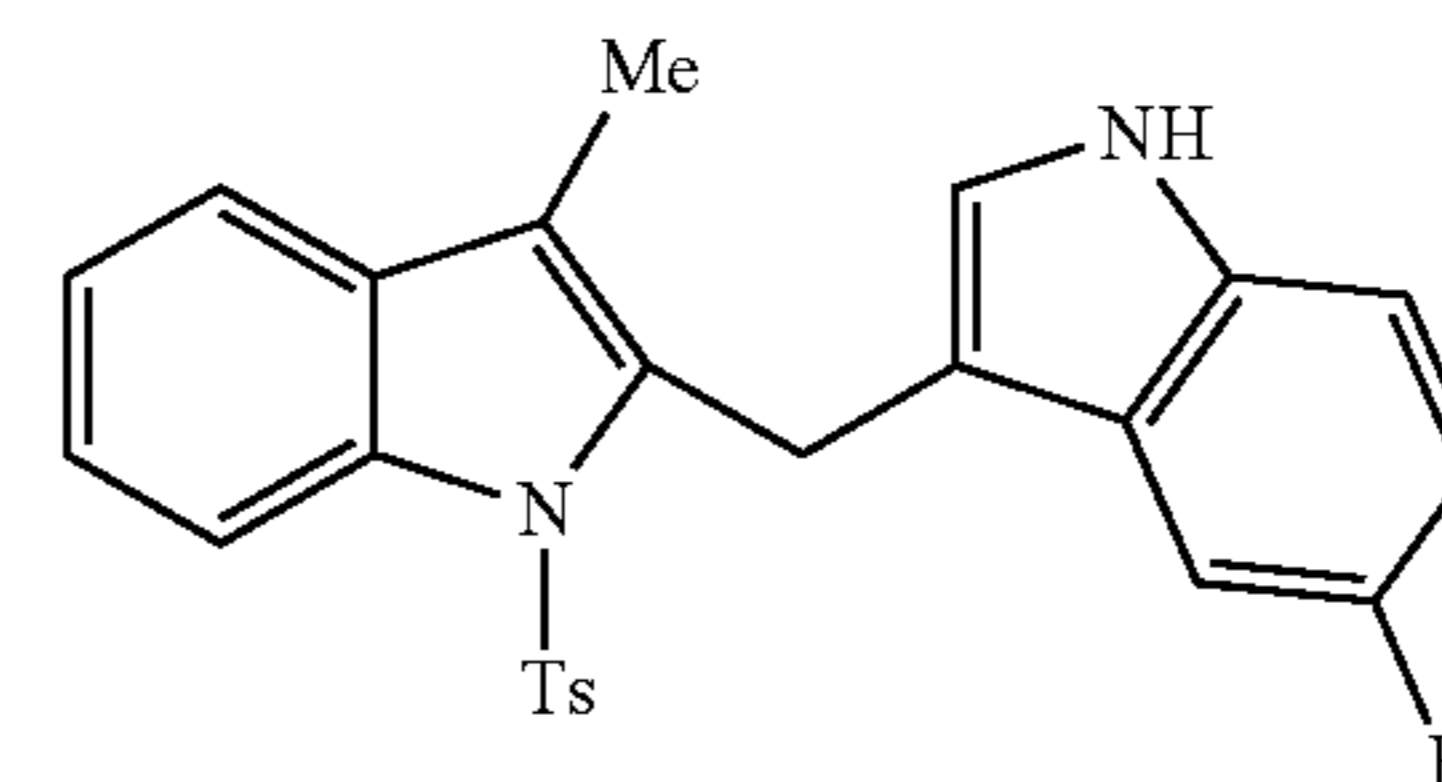
40

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9d

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9f

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Compound 9e was isolated as a yellow oil (29 mg, 68% yield). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 8.21 (d, J=8.0 Hz, 1H), 7.69 (s, 1H), 7.45-7.34 (m, 4H), 7.33-7.26 (m, 2H), 7.20 (d, J=8.4 Hz, 1H), 7.00 (d, J=8.0 Hz, 1H), 6.93 (d, J=8.4 Hz, 2H), 6.56 (d, J=1.2 Hz, 1H), 4.50 (s, 2H), 2.46 (s, 3H), 2.24 (s, 3H), 2.20 (s, 3H). <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>): δ 144.2, 136.9, 136.3, 135.6, 134.8, 131.5, 129.5, 128.9, 127.6, 126.6, 124.4, 123.9, 123.5, 123.0, 118.8, 118.7, 117.6, 115.4, 113.4, 110.9, 22.2, 21.9, 21.7, 9.5. IR (neat) ν 3360, 2944, 2925, 1652, 1521 cm<sup>-1</sup>. HRMS (ESI) for C<sub>26</sub>H<sub>24</sub>N<sub>2</sub>O<sub>2</sub>S (M+Na), 451.1451 (Calc.), found 451.1448

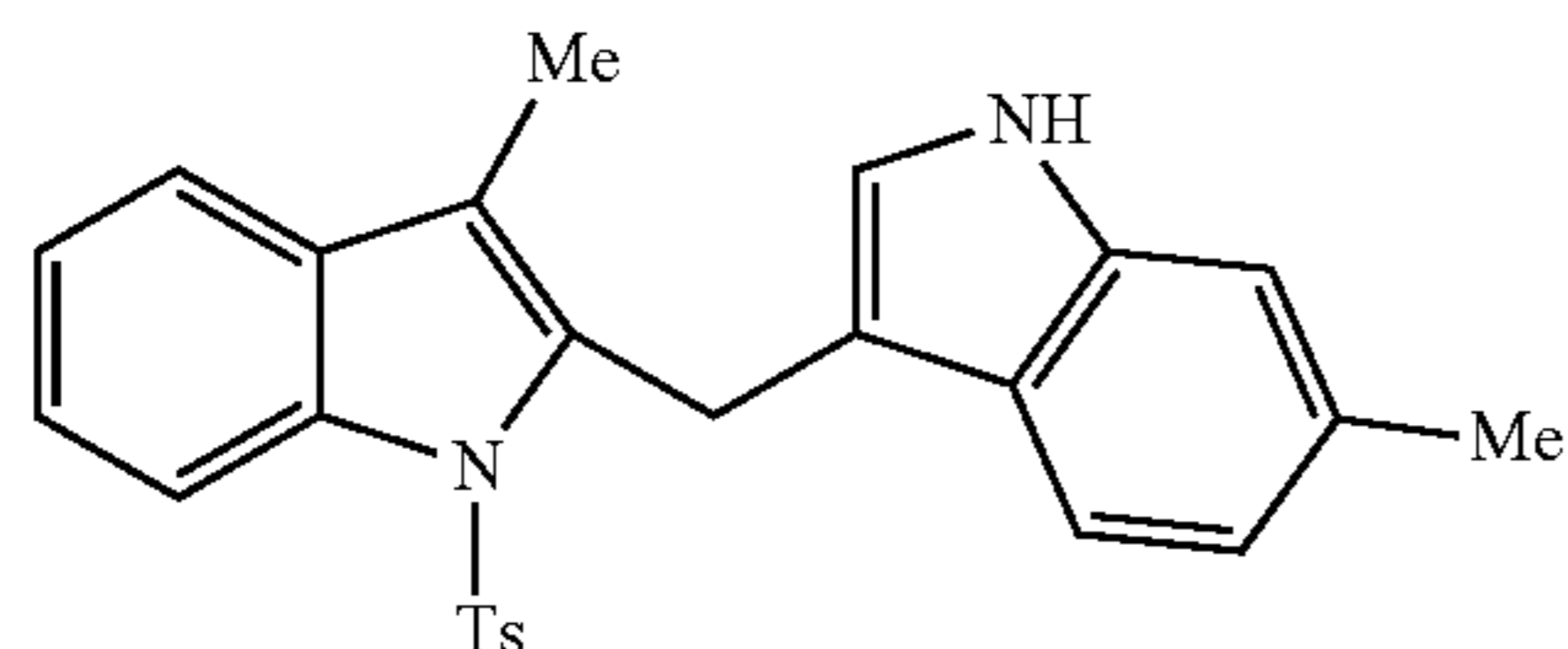
Compound 9f was isolated as yellow oil (14 mg, 63%). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 8.20 (d, J=5.0 Hz, 1H), 7.86 (s, 1H), 7.54 (d, J=2.0 Hz, 1H), 7.44 (d, J=5.0 Hz, 1H), 7.38 (d, J=10.0 Hz, 2H), 7.32-7.27 (m, 2H), 7.20 (d, J=10.0 Hz, 1H), 7.11 (dd, J=10.0, 2.0 Hz, 1H), 6.96 (d, J=10.0 Hz, 2H), 6.71 (s, 1H), 4.46 (s, 2H), 2.25 (s, 3H), 2.23 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ 144.4, 137.0, 136.3, 135.0, 134.7, 131.5, 129.6, 128.4, 126.5, 125.4, 124.6, 124.4, 123.6, 122.5, 118.9, 118.6, 117.8, 115.4, 113.8, 112.2, 22.3, 21.8, 9.5. IR (neat) ν 3399, 2926, 2253, 1726, 1598. HRMS (ESI) m/z calcd for C<sub>25</sub>H<sub>21</sub>ClN<sub>2</sub>O<sub>2</sub>S (M+Na)<sup>+</sup> 471.0904, found 471.0905.

9g

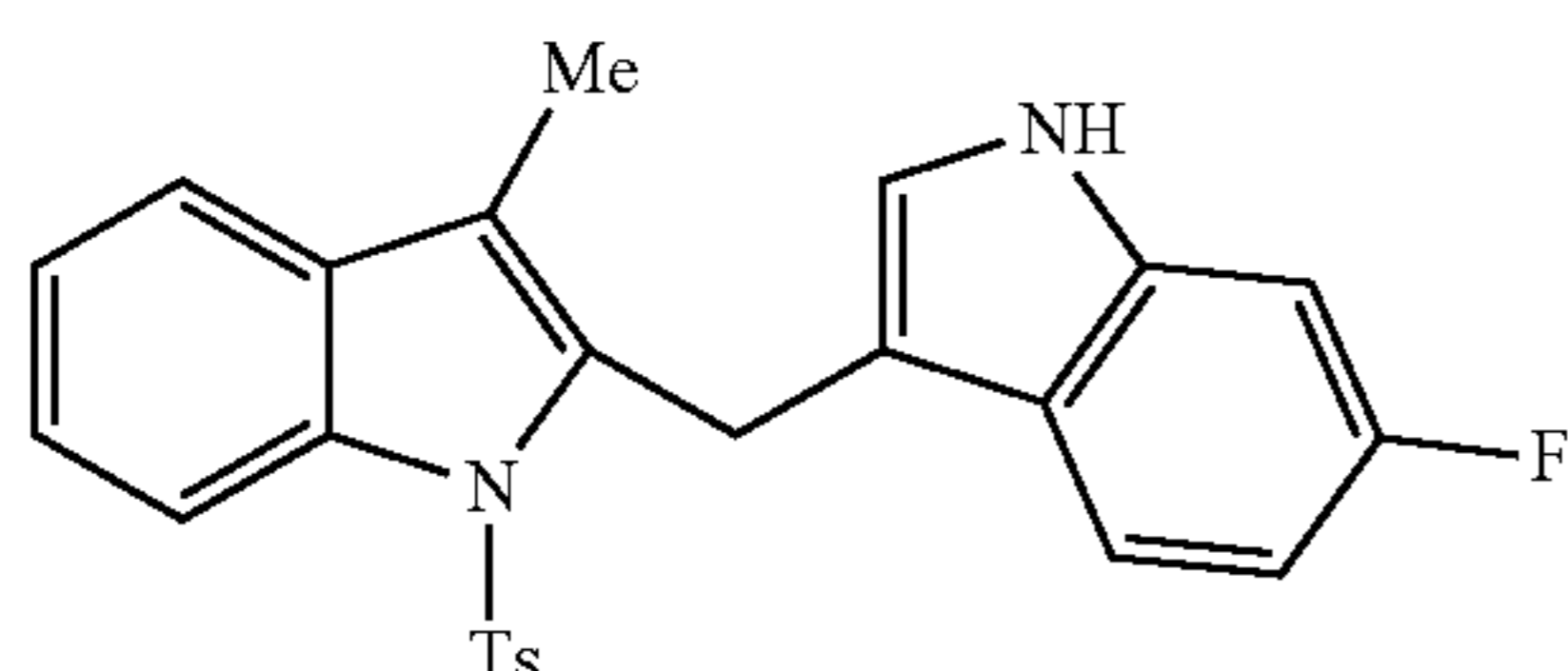
Compound 9g was isolated as a brown solid (43 mg, 70% yield). mp=55-60° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>): δ 2.158 (s, 3H), 2.161 (s, 3H), 4.38 (s, 2H), 6.67 (d, J=0.5 Hz, 1H), 6.81 (td, J=7.5, 2.5 Hz, 1H), 6.86 (d, J=8.5 Hz, 2H), 7.09-7.12 (m, 2H), 7.18-7.23 (m, 2H), 7.28 (d, J=8.5, 2H), 7.36 (d, J=8.5, 1H), 7.78 (broad s, 1H), 8.12 (d, J=7.5, 1H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 9.5, 21.7, 22.4, 104.0 (d, J=22.9 Hz), 110.5 (d, J=26.7 Hz), 111.8 (d, J=9.1 Hz), 114.1,

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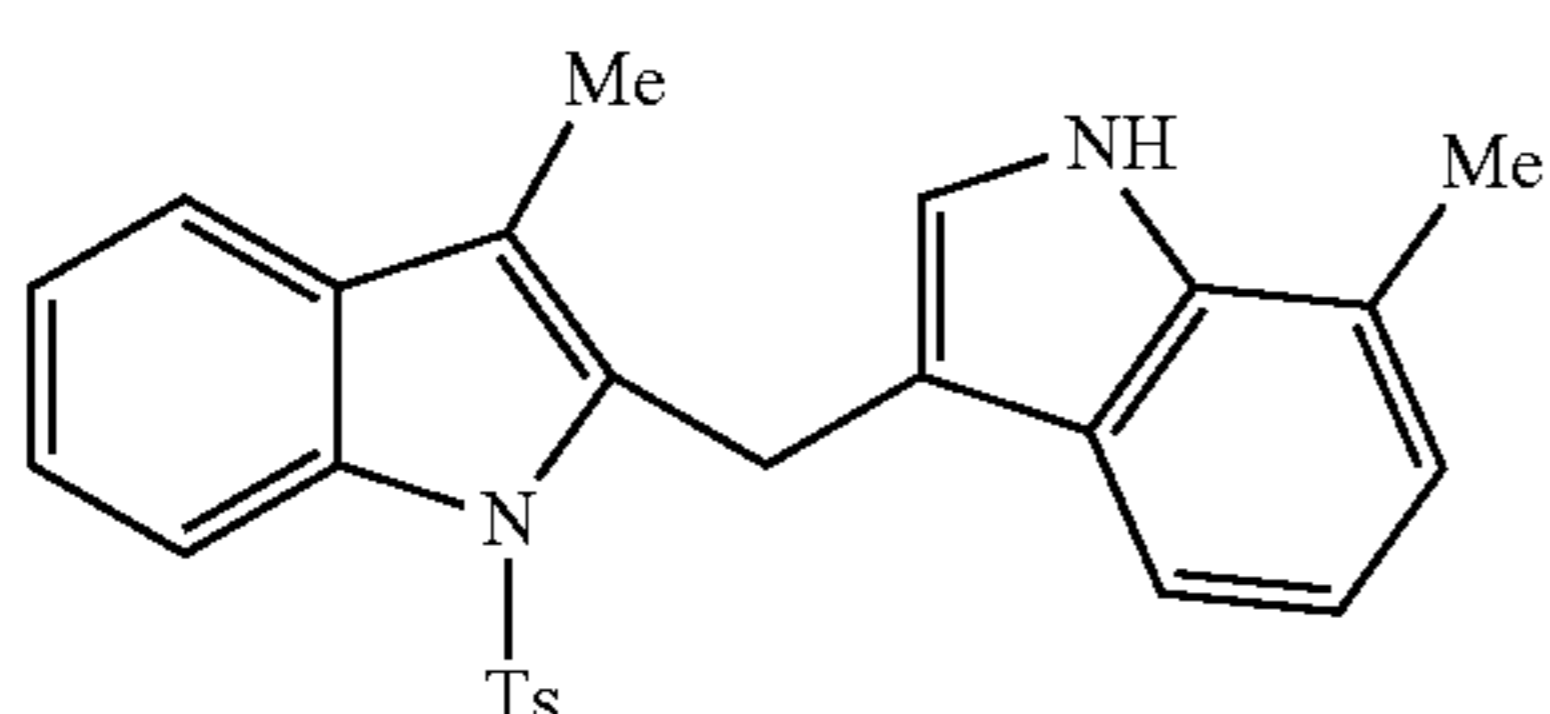
115.4, 117.8, 118.9, 123.6, 124.6, 124.9, 126.5, 129.5, 131.5, 132.9, 135.1, 136.3, 137.0, 144.3, 158.0 (d,  $J=232.9$  Hz).  $\delta$  IR (neat) 1358.92, 1486.49, 1581.04, 1597.66, 1710.37, 2853.40, 2923.35, 3422.05  $\nu$   $\text{cm}^{-1}$ . HRMS (ESI)  $M/Z$  calcd. for  $\text{C}_{25}\text{H}_{21}\text{FN}_2\text{O}_2\text{S}$  ( $M+\text{Na}$ ) $^+$  455.1200, found 455.1200.



Compound 9h was isolated as yellow oil (33 mg, 77%).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ , TMS):  $\delta$  8.20 (d,  $J=4.0$  Hz, 1H), 7.67 (s, 1H), 7.46 (d,  $J=8.0$  Hz, 1H), 7.43-7.41 (m, 1H), 7.34 (d,  $J=8.0$  Hz, 2H), 7.31-7.25 (m, 1H), 7.23-7.19 (m, 1H), 7.08 (s, 1H), 6.93-6.90 (m, 3H), 6.58 (s, 1H), 4.50 (s, 2H), 2.44 (s, 3H), 2.23 (s, 3H), 2.22 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  144.2, 136.93, 136.91, 136.3, 135.7, 132.0, 131.5, 129.5, 126.6, 125.3, 124.4, 123.5, 122.3, 121.5, 118.8, 118.7, 117.5, 115.4, 113.7, 111.2, 22.3, 22.0, 21.7, 9.5. IR (neat)  $\nu$  3663, 3446, 2949, 2882, 1734, 1717, 1652, 1537. HRMS (ESI)  $m/z$  calcd for  $\text{C}_{26}\text{H}_{24}\text{N}_2\text{O}_2\text{S}$  ( $M+\text{Na}$ ) $^+$  451.1451, found 451.1445.



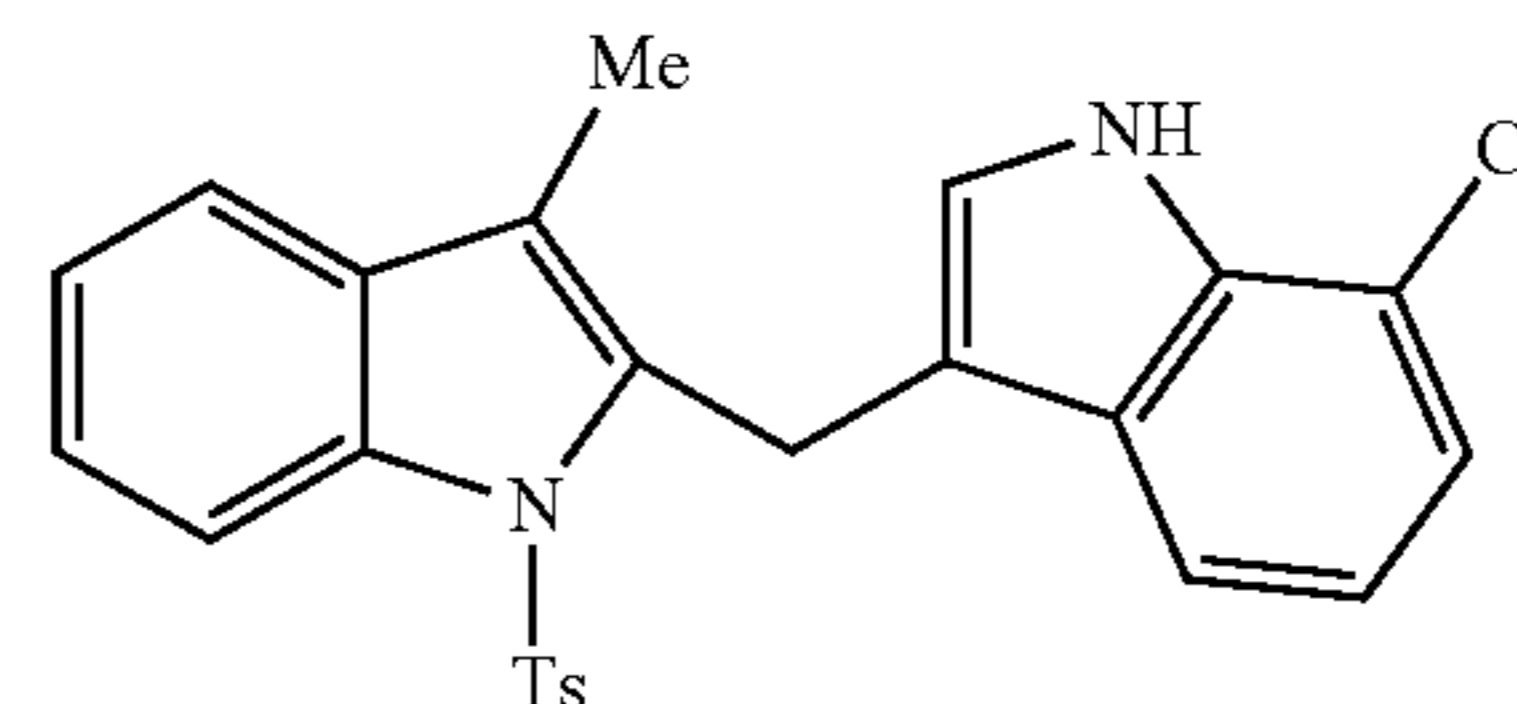
Compound 9i was isolated as colorless oil (30 mg, 70%).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ , TMS):  $\delta$  8.20 (d,  $J=8.0$  Hz, 1H), 7.80 (s, 1H), 7.49-7.43 (m, 2H), 7.33 (d,  $J=8.0$  Hz, 2H), 7.30-7.25 (m, 2H), 6.98 (dd,  $J=9.6, 2.4$  Hz, 1H), 6.93 (d,  $J=8.0$  Hz, 2H), 6.88-6.83 (m, 1H), 6.66-6.65 (m, 1H), 4.50 (s, 2H), 2.25 (s, 3H), 2.24 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  160.3 (d,  $J=236.8$  Hz), 144.3, 137.0, 136.3, 135.2, 131.4, 129.5, 126.5, 124.6, 124.0, 123.6, 123.2, 119.9 (d,  $J=10$  Hz), 118.8, 117.7, 115.4, 114.1, 108.5 (d,  $J=24$  Hz), 97.5 (d,  $J=26$  Hz), 22.3, 21.7, 9.5. IR (neat)  $\nu$  3649, 2948, 1734, 1692, 1641, 1513. HRMS (ESI)  $m/z$  calcd for  $\text{C}_{25}\text{H}_{22}\text{N}_2\text{O}_2\text{SF}$  ( $M+\text{Na}$ ) $^+$  455.1200, found 455.1198.



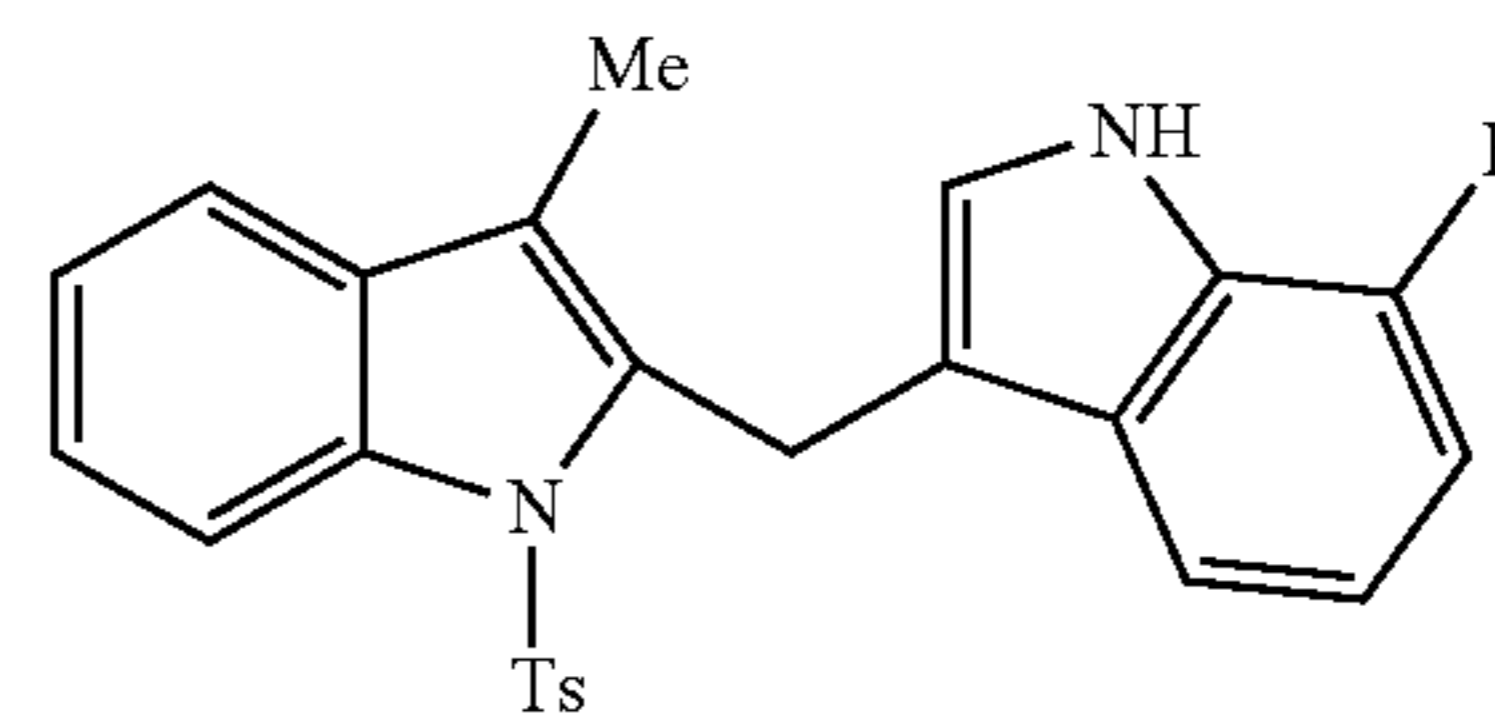
Compound 9j was isolated as a yellow oil (28 mg, 67% yield).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ , TMS):  $\delta$  8.20 (d,  $J=8.0$  Hz, 1H), 7.69 (s, 1H), 7.43 (d,  $J=7.6$  Hz, 2H), 7.37-7.22 (m, 4H), 6.98 (m, 2H), 6.88 (d,  $J=8.4$  Hz, 2H), 6.63 (d,  $J=1.2$  Hz, 1H), 4.51 (s, 2H), 2.42 (s, 3H), 2.22 (s, 3H), 2.22 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  144.1, 137.0, 136.4, 135.6,

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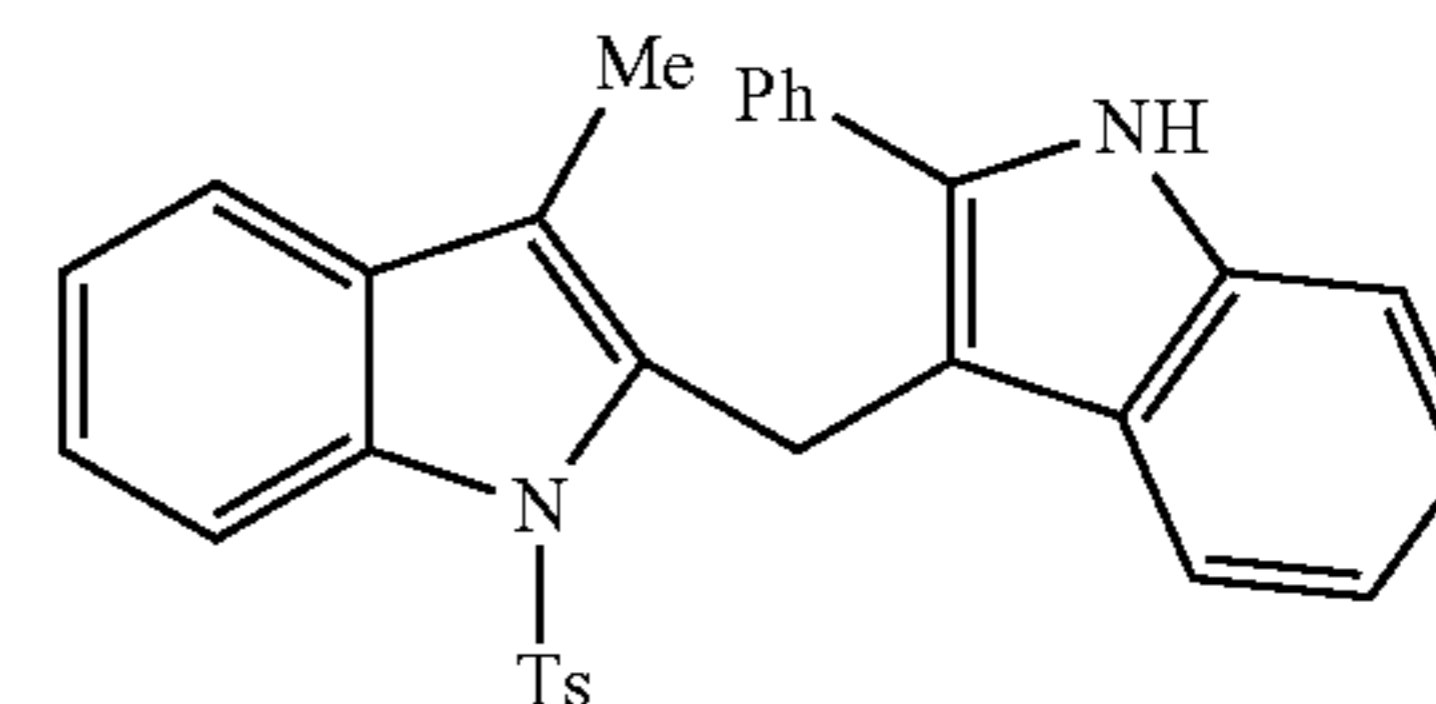
131.5, 129.4, 126.9, 126.5, 124.5, 123.5, 122.73, 122.69, 120.3, 119.9, 118.8, 117.6, 116.9, 115.4, 114.4, 22.5, 21.7, 16.8, 9.5. IR (neat)  $\nu$  3388, 2922, 2854, 1652, 1457  $\text{cm}^{-1}$ . HRMS (ESI) for  $\text{C}_{26}\text{H}_{24}\text{N}_2\text{O}_2\text{S}$  ( $M+\text{Na}$ ), 451.1451 (Calc.), found 451.1449.



Compound 9k was isolated as colorless oil (26 mg, 59%).  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ , TMS):  $\delta$  8.21 (d,  $J=5.0$  Hz, 1H), 7.95 (s, 1H), 7.47-7.43 (m, 2H), 7.33-7.24 (m, 3H), 7.14 (d,  $J=5.0$  Hz, 1H), 7.01-6.98 (m, 1H), 6.85 (d,  $J=10.0$  Hz, 2H), 6.67 (s, 1H), 4.50 (s, 2H), 2.26 (s, 3H), 2.22 (s, 3H).  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ ):  $\delta$  144.2, 137.1, 136.4, 135.0, 133.6, 131.2, 129.3, 128.8, 126.2, 124.7, 123.7, 123.5, 121.5, 120.5, 118.8, 117.8, 117.6, 116.7, 115.3, 114.9, 22.4, 21.7, 9.5. IR (neat)  $\nu$  3674, 3384, 2949, 1734, 1717, 1678, 1641, 1631, 1513. HRMS (ESI)  $m/z$  calcd for  $\text{C}_{25}\text{H}_{21}\text{ClN}_2\text{O}_2\text{S}$  ( $M+\text{Na}$ ) $^+$  471.0904, found 471.0897.



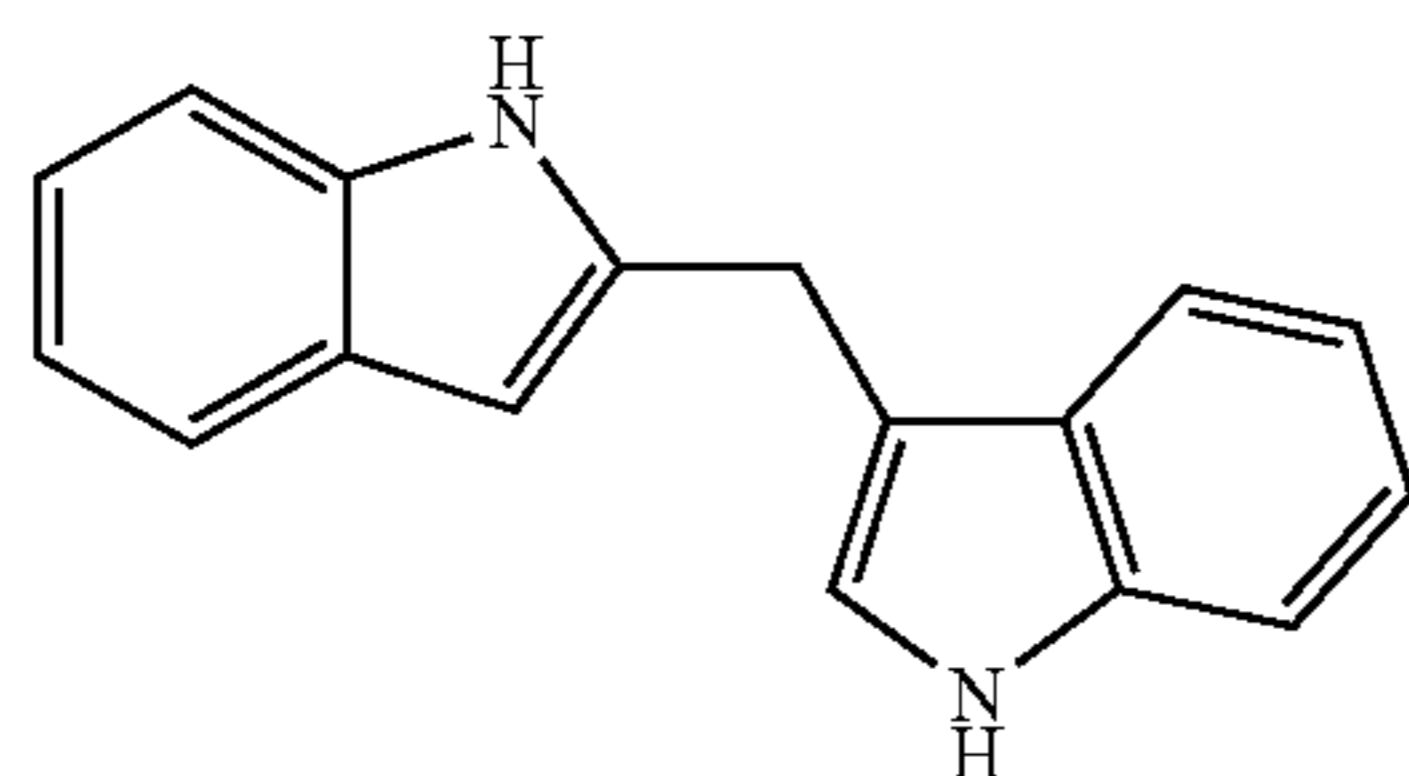
Compound 9l was isolated as brown oil (35 mg, 81%).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ , TMS):  $\delta$  8.13 (d,  $J=8.0$  Hz, 1H), 7.87 (s, 1H), 7.39-7.37 (m, 1H), 7.25-7.18 (m, 6H), 6.91 (ddd,  $J=20.0, 12.0, 4.0$  Hz, 1H), 6.83 (d,  $J=8.0$  Hz, 2H), 6.62 (s, 1H), 4.44 (s, 2H), 2.18 (s, 3H), 2.16 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  149.7 (d,  $J=242.8$  Hz), 144.3, 137.1, 136.4, 135.1, 131.2 (d,  $J=29.8$  Hz), 129.9, 129.2 (d,  $J=40$  Hz), 126.4, 124.6, 123.7, 123.6, 120.0 (d,  $J=6.1$  Hz), 118.8, 117.7, 115.4, 115.0, 114.9, 114.8, 107.0 (d,  $J=15$  Hz), 22.4, 21.7, 9.5. IR (neat)  $\nu$  3801, 3344, 1749, 1734, 1652, 1530. HRMS (ESI)  $m/z$  calcd for  $\text{C}_{25}\text{H}_{21}\text{FN}_2\text{O}_2\text{S}$  ( $M+\text{Na}$ ) $^+$  455.1200, found 455.1202.



Compound 9m was isolated as colorless oil (35 mg, 71%).  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ , TMS):  $\delta$  8.25 (d,  $J=5.0$  Hz, 1H), 8.04 (s, 1H), 7.51 (d,  $J=10.0$  Hz, 2H), 7.41-7.22 (m, 9H), 7.08 (t,  $J=10.0$  Hz, 1H), 7.00-6.94 (m, 3H), 6.84-6.81 (m, 1H), 4.66 (s, 2H), 2.26 (s, 3H), 1.81 (s, 3H).  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ ):  $\delta$  144.3, 137.0, 136.6, 135.9, 135.2, 134.3, 133.2, 131.7, 129.6, 129.3, 129.1, 128.4, 128.0,

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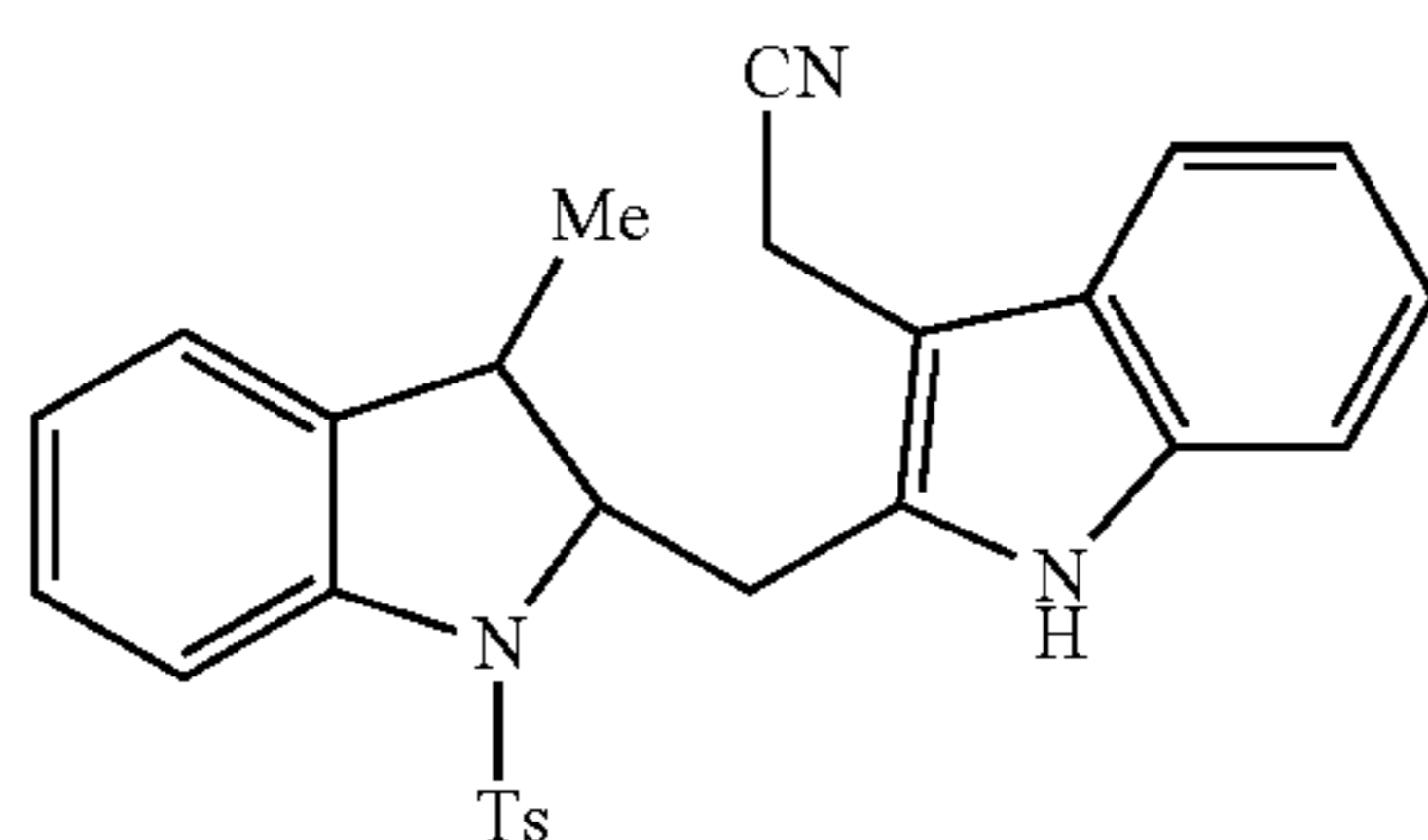
126.3, 124.5, 123.4, 122.4, 120.0, 119.6, 118.6, 118.0, 115.2, 110.9, 109.4, 24.0, 21.8, 9.0. IR (neat)  $\nu$  3675, 2948, 1749, 1734, 1661, 1513. HRMS (ESI)  $m/z$  calcd for  $C_{31}H_{26}N_2O_2S$  ( $M+Na$ )<sup>+</sup> 513.1607, found 513.1617.



3-((1H-indol-2-yl)methyl)-1H-indole

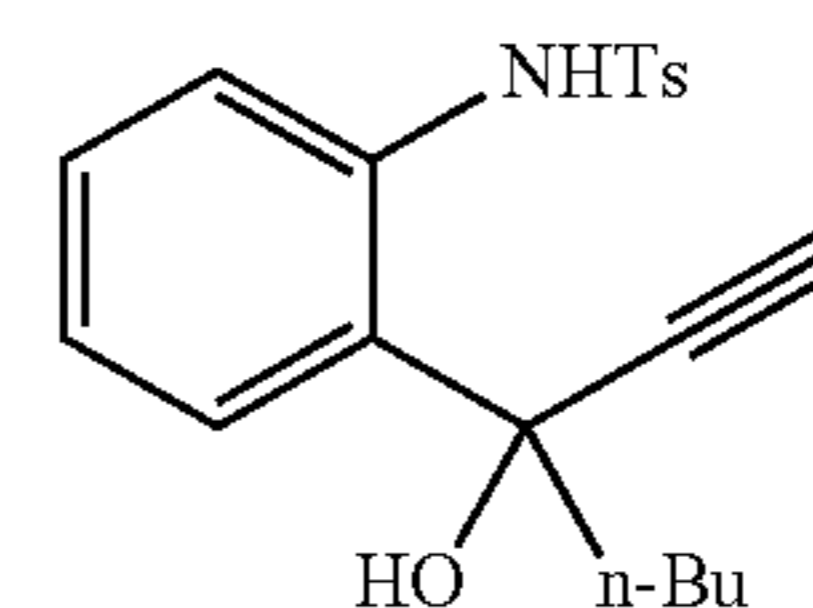
Neat compound 6a (49 mg, 0.18 mmol) was heated at 160° C. for 45 min, the residue was purified by flash column chromatography on silica gel (Hexane/EtOAc=8:1 to 4:1) to provide 25 mg of free bisindole 10 (70% yield) as a pinkish solid (m.p.=136-137° C.).

<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  4.26 (s, 2H), 6.38 (m, 1H), 7.00 (m, 1H), 7.07 (m, 3H), 7.20 (m, 2H), 7.34 (d, J=8.0 Hz, 1H), 7.53 (m, 2H), 7.79 (br, 1H), 7.92 (br, 1H). <sup>1</sup>H NMR (400 MHz, DMSO-d<sub>6</sub>):  $\delta$  4.19 (s, 2H), 6.17 (s, 1H), 6.95 (m, 3H), 7.07 (td, J=6.4, 0.8 Hz, 1H), 7.24 (d, J=1.6 Hz, 1H), 7.27 (d, J=6.4 Hz, 1H), 7.37 (d, J=6.4 Hz, 1H), 7.39 (d, J=6.4 Hz, 1H), 7.50 (d, J=6.4 Hz, 1H), 10.89 (br, 2H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): 138.4, 136.6, 136.1, 129.0, 127.4, 122.8, 122.5, 121.1, 120.0, 119.9, 119.7, 119.2, 113.0, 111.4, 110.6, 100.2, 24.6. IR (film): 3403, 2926, 1458, 1418, 1342, 1285, 908 cm<sup>-1</sup>. All spectroscopic data are in accordance with literature. Zhang, J.; Zhu, D.; Yu, C.; Wan, C.; Wang, Z. *Org. Lett.* 2010, 12, 2841.



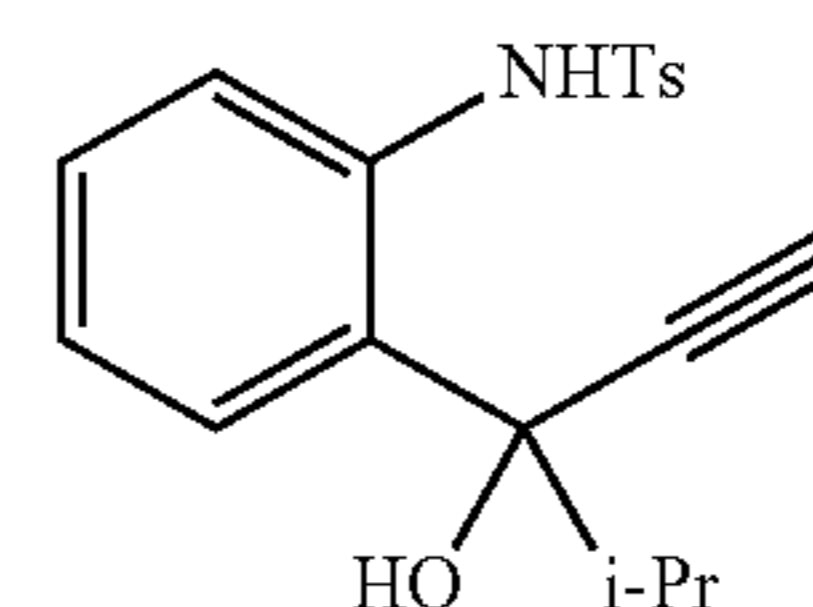
Compound 10a was isolated as colorless oil (35 mg, 78%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  8.20 (d, J=8.0 Hz, 1H), 8.17 (s, 1H), 7.58-7.56 (m, 1H), 7.47 (d, J=8.0 Hz, 1H), 7.38-7.25 (m, 4H), 7.17-7.14 (m, 3H), 6.84 (d, J=8.0 Hz, 2H), 4.56 (s, 2H), 3.89 (s, 2H), 2.33 (s, 3H), 2.19 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>):  $\delta$  145.1, 137.1, 135.6, 135.2, 132.9, 131.6, 131.0, 129.8, 127.4, 126.2, 125.5, 124.1, 122.6, 120.5, 119.3, 119.2, 118.4, 118.0, 115.5, 111.3, 100.6, 23.3, 21.7, 13.3, 9.6. IR (neat)  $\nu$  3337, 1734, 1717, 1652, 1513. HRMS (ESI)  $m/z$  calcd for  $C_{27}H_{23}N_3O_2S$  ( $M+Na$ )<sup>+</sup> 476.1403, found 476.1407.

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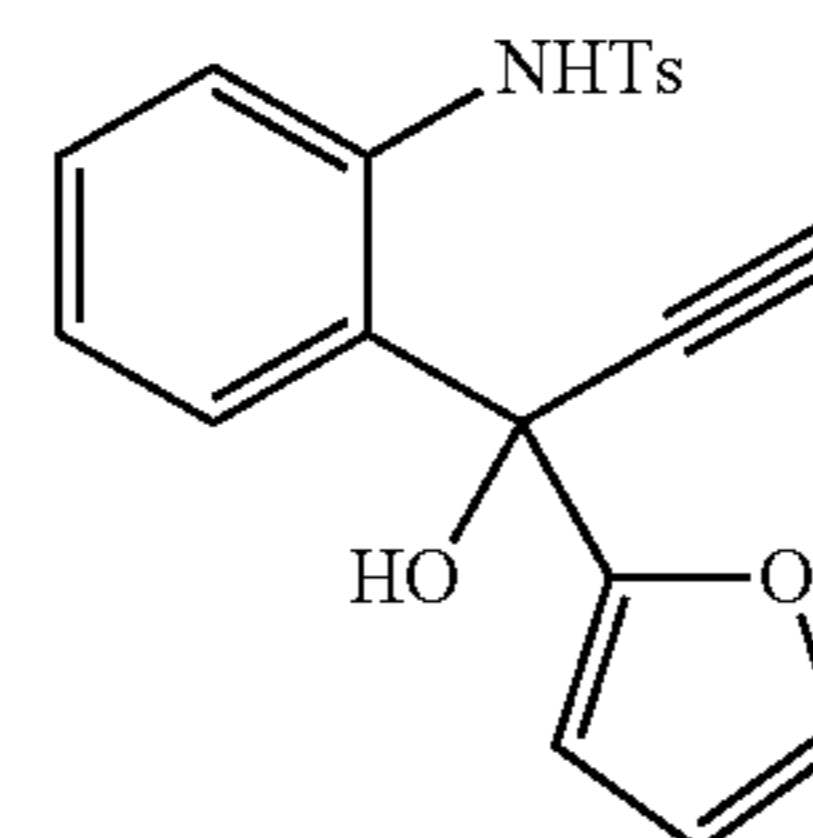
11a

Compound 11a was isolated as white solid (1.86 g, 61%). mp=85-86° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  9.08 (s, 1H), 7.73 (d, J=8.0 Hz, 2H), 7.65 (d, J=8.0 Hz, 1H), 7.56 (dd, J=8.0, 1.6 Hz, 1H), 7.26-7.21 (m, 3H), 7.01 (t, J=8.0 Hz, 1H), 3.02 (s, 1H), 2.78 (s, 1H), 2.36 (s, 3H), 1.79-1.71 (m, 1H), 1.67-1.60 (m, 1H), 1.38-1.32 (m, 1H), 1.17-0.98 (m, 3H), 0.80 (t, J=8.0 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>):  $\delta$  143.9, 137.1, 135.7, 130.2, 129.8, 129.1, 128.7, 127.2, 123.5, 120.2, 84.8, 76.2, 76.0, 42.6, 27.0, 22.5, 21.6, 14.1. IR (neat)  $\nu$  3675, 2949, 2877, 1734, 1717, 1692, 1641, 1513. HRMS (ESI)  $m/z$  calcd for  $C_{20}H_{23}NO_3S$  ( $M+Na$ )<sup>+</sup> 380.1291, found 380.1293.



11b

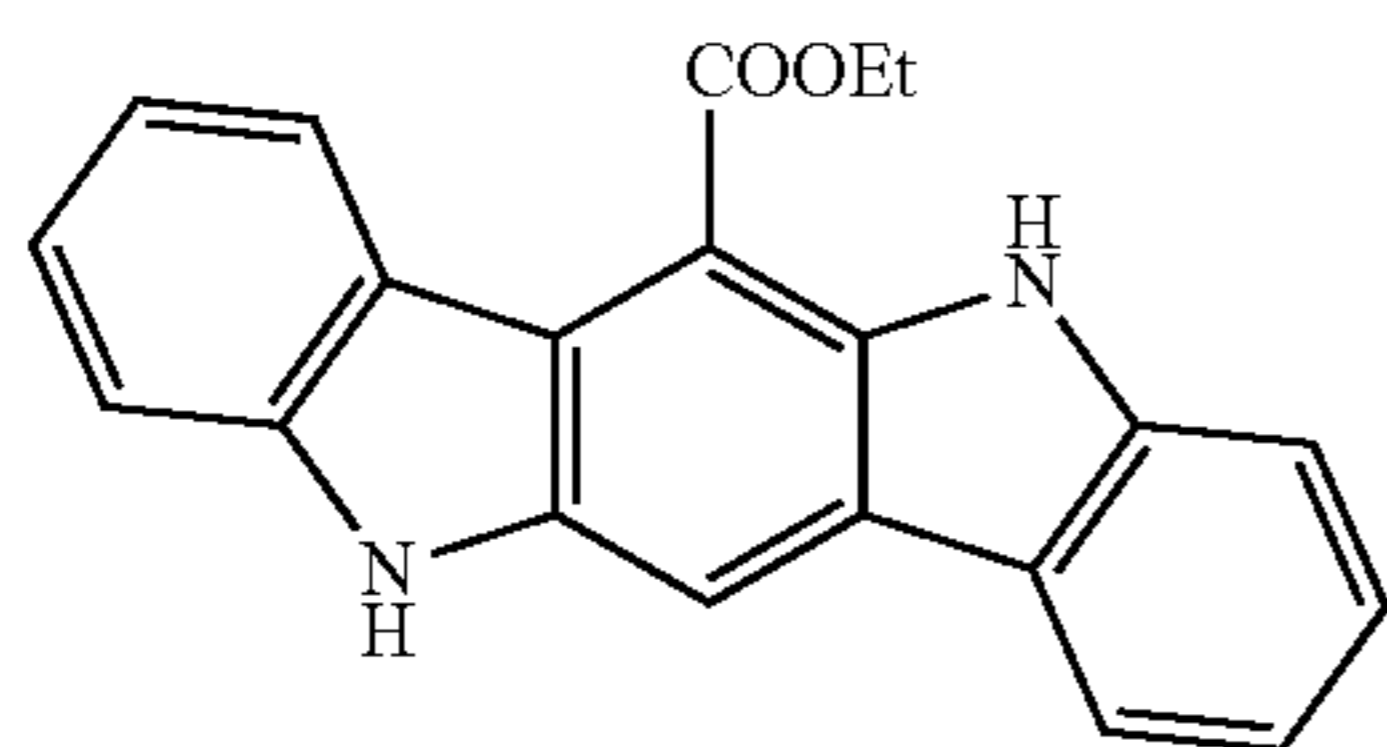
Compound 11b was isolated as colorless solid (2.15 g, 76%). mp=111-113° C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  8.97 (s, 1H), 7.70 (d, J=8.0 Hz, 2H), 7.65 (d, J=8.0 Hz, 1H), 7.56 (d, J=8.0 Hz, 1H), 7.26-7.21 (m, 3H), 7.00 (t, J=8.0 Hz, 1H), 2.99 (s, 1H), 2.78 (s, 1H), 2.37 (s, 3H), 1.79 (m, 1H), 1.04 (d, J=8.0 Hz, 3H), 0.44 (d, J=8.0 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>):  $\delta$  144.0, 137.4, 135.8, 130.0, 129.9, 129.8, 129.3, 127.3, 123.4, 120.9, 82.6, 80.4, 77.6, 37.2, 21.7, 18.5, 17.2. IR (neat)  $\nu$  3676, 2947, 1734, 1717, 1678, 1641, 1530. HRMS (ESI)  $m/z$  calcd for  $C_{19}H_{21}NO_3S$  ( $M+Na$ )<sup>+</sup> 366.1134, found 366.1137.



11d

Compound 11d was isolated as colorless solid (0.15 g, 67%). mp=123-124° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  8.69 (s, 1H), 7.69 (d, J=5.0 Hz, 2H), 7.62 (d, J=10 Hz, 1H), 7.40-7.34 (m, 2H), 7.28-7.24 (m, 1H), 7.20 (d, J=10 Hz, 2H), 7.01-6.98 (m, 1H), 6.30-6.29 (m, 1H), 6.17 (d, J=5.0 Hz, 1H), 3.43 (s, 1H), 2.84 (s, 1H), 2.37 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>):  $\delta$  152.9, 143.9, 143.8, 137.1, 136.5, 130.1, 129.8, 129.0, 127.8, 127.7, 123.5, 119.6, 110.9, 109.2, 82.4, 76.9, 71.3, 21.8. IR (neat)  $\nu$  3681, 2944, 1734, 1652, 1537. HRMS (ESI)  $m/z$  calcd for  $C_{20}H_{17}NO_4S$  ( $M+Na$ )<sup>+</sup> 390.0771, found 390.0790.

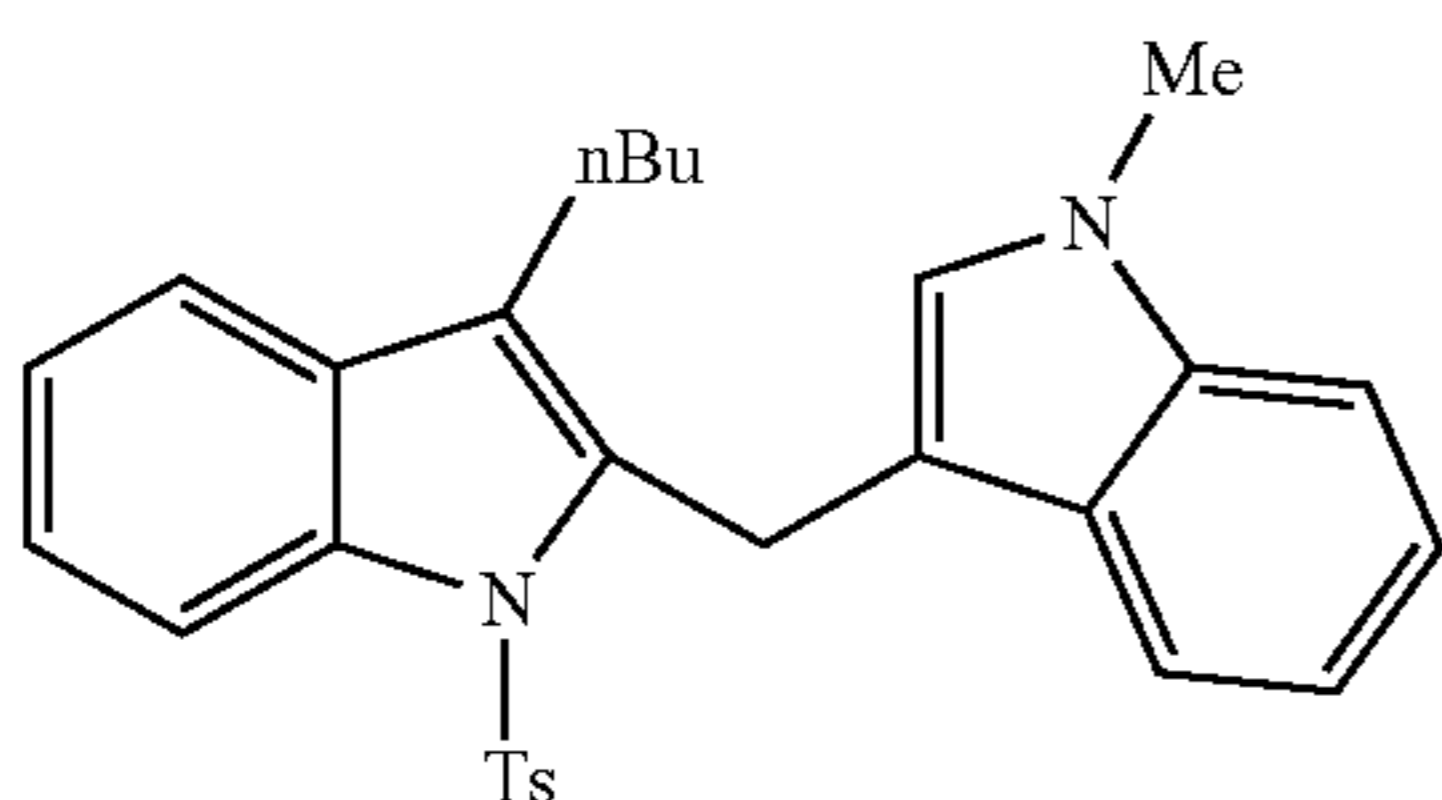
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Ethyl 5,11-dihydroindolo[3,2-b]carbazole-6-carboxylate

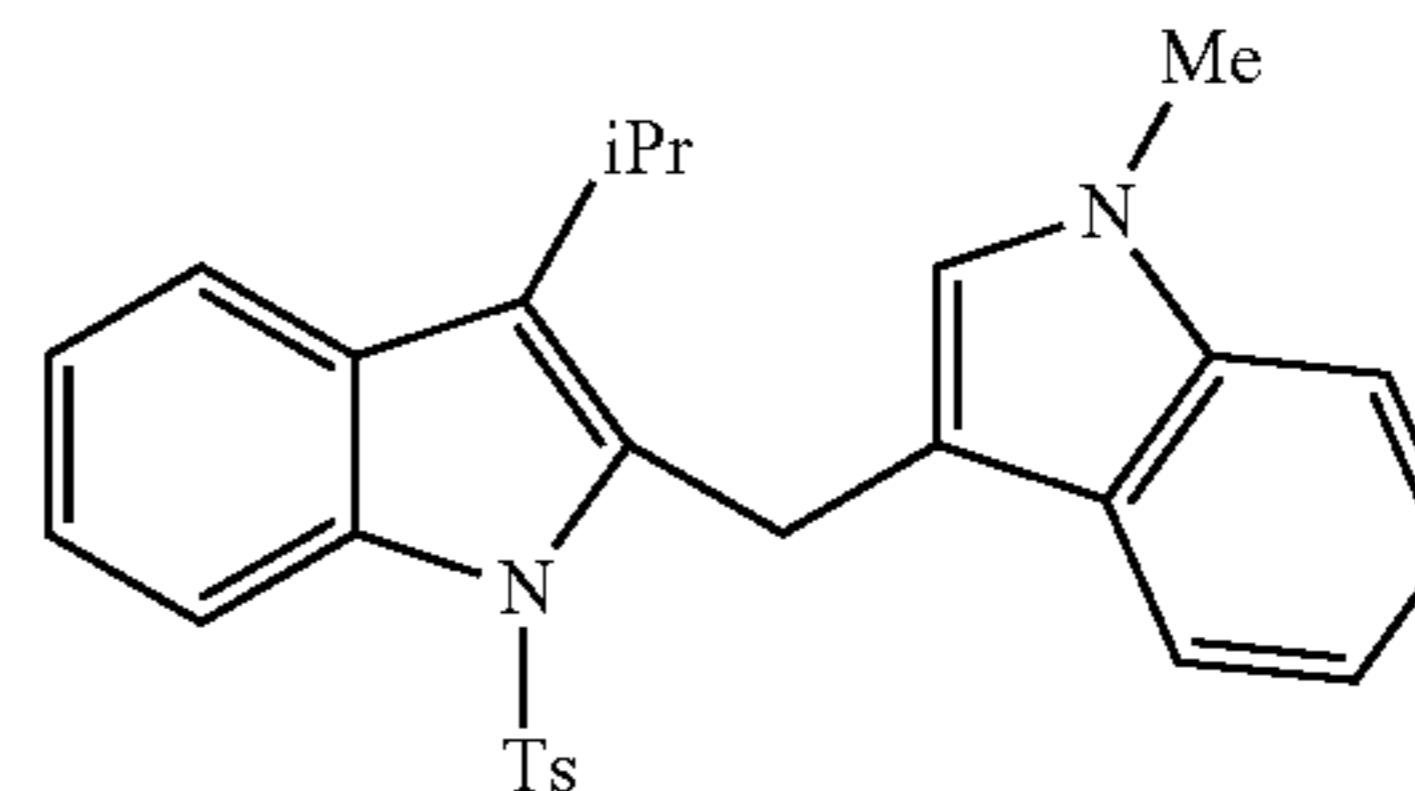
To a solution of bisindole 10 (57 mg, 0.23 mmol) in 1.5 ml of THF at 0° C. under Ar was added 0.03 ml of pyridine quickly followed by ethyl oxalyl chloride (0.054 ml, 0.35 mmol) slowly over 10 min. The reaction was stirred for 6 h. The mixture was diluted with EtOAc, washed with 1 M HCl, then NaHCO<sub>3</sub> and dried over MgSO<sub>4</sub>. The residue was purified by flash column chromatography on silica gel (Hexane/EtOAc=3:1 to 2:1). The purified intermediate was dissolved in 4 mL of dioxane and 0.1 mL of MeSO<sub>3</sub>H was added dropwise. The solution was heated to reflux for 1 h and then cooled down to room temperature. Silica was added and the residue was purified by flash column chromatography on silica gel (Hexane/CH<sub>2</sub>Cl<sub>2</sub>=1:1) to yield a yellow solid (40 mg, 52% yield for two steps, m.p.=217-218° C.).

<sup>1</sup>H NMR (400 MHz, acetone-d<sub>6</sub>): δ 1.43 (t, J=6.8 Hz, 3H), 4.57 (q, J=6.8 Hz, 2H), 7.04 (qd, J=7.6, 0.8 Hz, 2H), 2.95 (td, J=7.2, 1.2 Hz, 2H), 7.40 (d, J=8.0 Hz, 1H), 7.51 (d, J=8.0 Hz, 1H), 8.04 (d, J=8.0 Hz, 1H), 8.35 (s, 1H), 8.83 (d, J=8.0 Hz, 1H), 10.40 (br, 2H). <sup>13</sup>C NMR (100 MHz, acetone-d<sub>6</sub>): 168.9, 143.4, 142.7, 138.3, 137.1, 127.7, 127.6, 127.2, 125.1, 123.7, 123.5, 122.5, 121.5, 120.3, 119.4, 112.5, 111.9, 108.2, 106.7, 62.2, 15.5. IR (film): 3393, 2976, 1675, 1610, 1510, 1455, 1416, 1295, 1111, 908, 870. All spectroscopic data are in accordance with literature. (Tholander, J; Bergman, J. *Tetrahedron*, 1999, 55, 6243.)

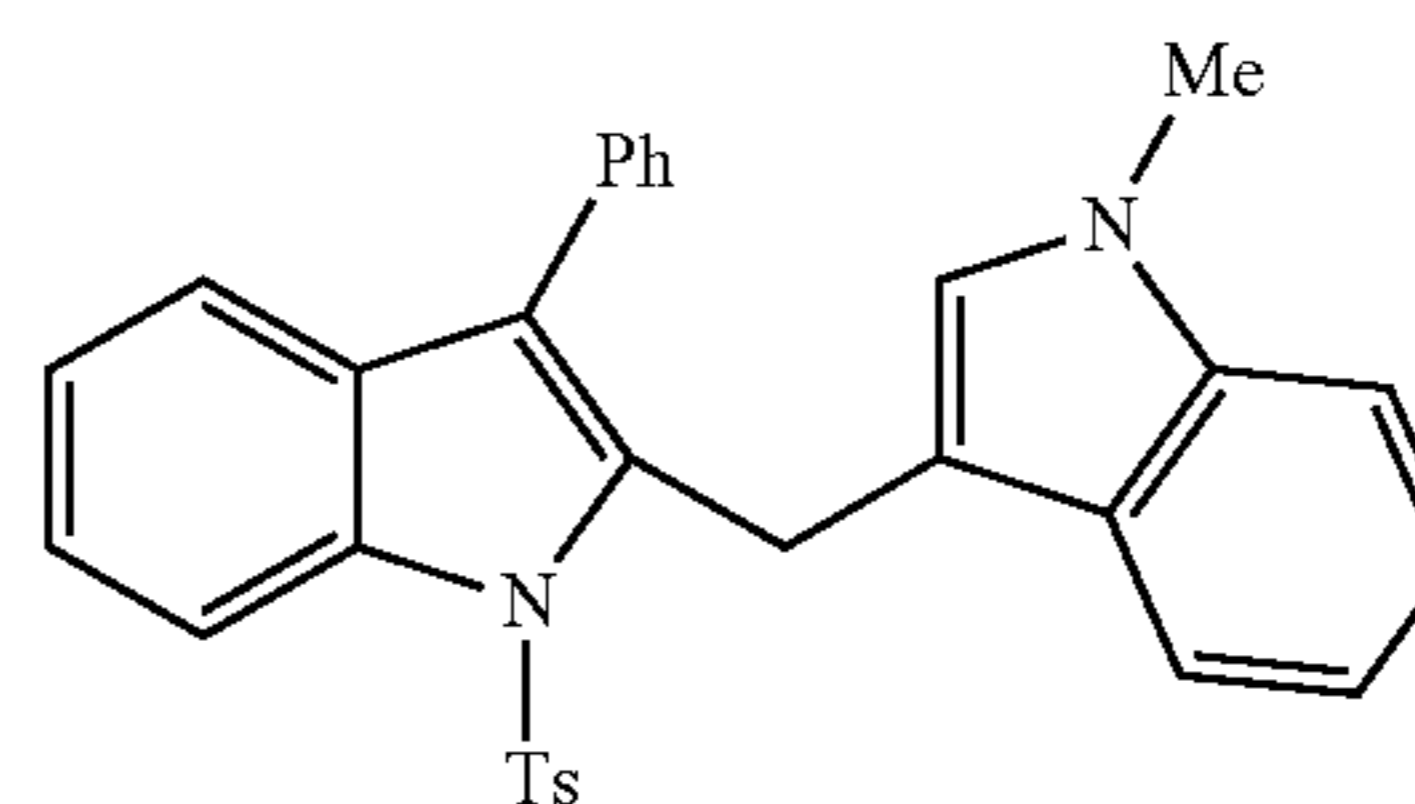


Compound 12a was isolated as yellow oil (16 mg, 65%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 8.24 (d, J=8.0 Hz, 1H), 7.61 (d, J=8.0 Hz, 1H), 7.48 (d, J=8.0 Hz, 1H), 7.32-7.24 (m, 4H), 7.20 (d, J=4.0 Hz, 2H), 7.10 (ddd, J=20.0, 12.0, 4.0 Hz, 1H), 6.86 (d, J=8.0 Hz, 2H), 6.34 (s, 1H), 4.51 (s, 2H), 3.51 (s, 3H), 2.69 (t, J=8.0 Hz, 2H), 2.24 (s, 3H), 1.51 (m, 2H), 1.28 (m, 2H), 0.84 (t, J=8.0 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 144.0, 137.3, 137.1, 136.4, 135.6, 130.9, 129.2, 127.74, 127.68, 126.5, 124.3, 123.4, 122.3, 121.7, 119.2, 119.1, 119.0, 115.6, 112.4, 109.2, 32.7, 32.4, 24.4, 22.9, 22.1, 21.7, 14.2. IR (neat) ν 3675, 2949, 1734, 1678, 1513. HRMS (ESI) m/z calcd for C<sub>29</sub>H<sub>30</sub>N<sub>2</sub>O<sub>2</sub>S (M+Na)<sup>+</sup> 493.1920, found 493.1932.

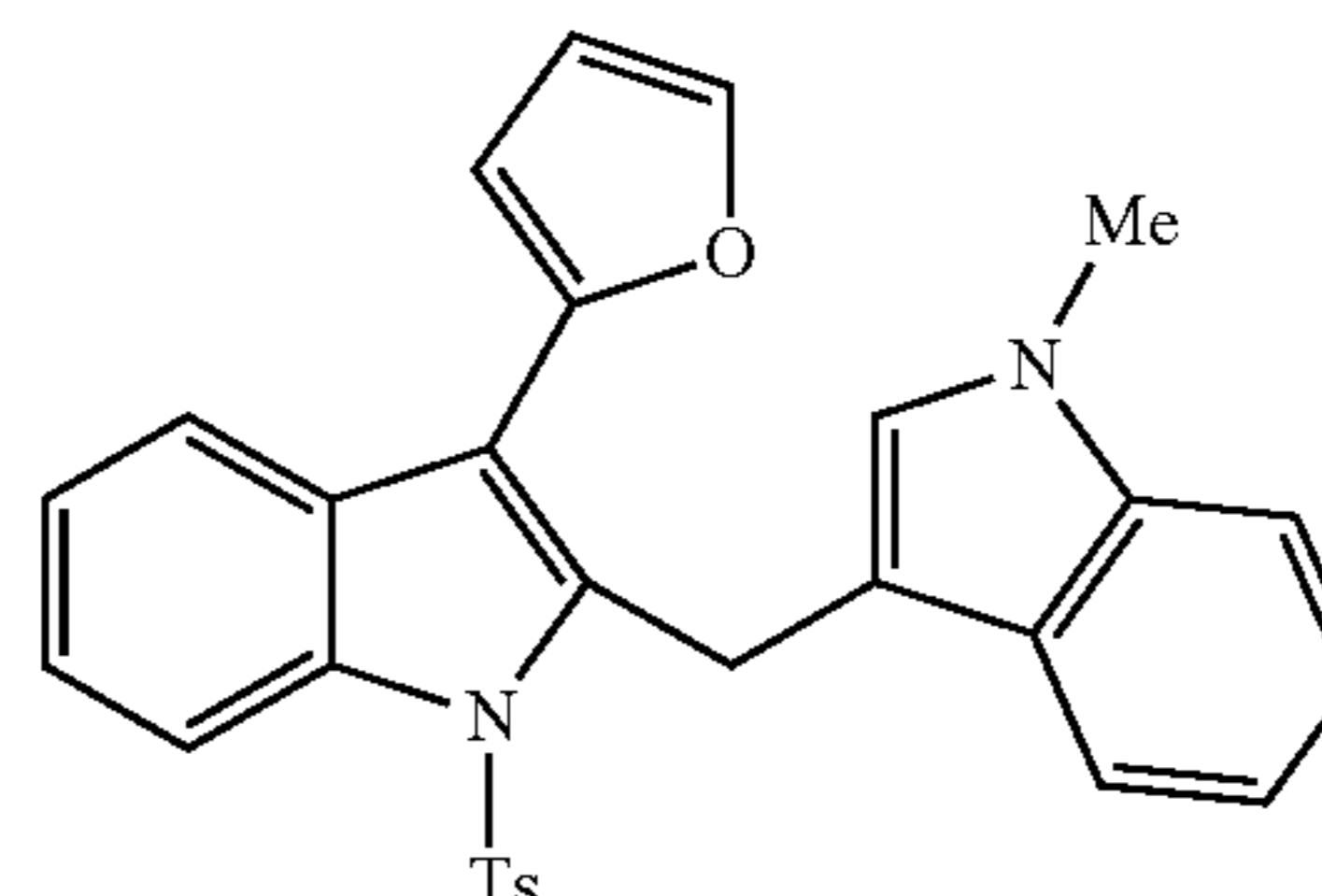
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Compound 12b was isolated as brown oil (38 mg, 83%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS): δ 8.32 (d, J=8.0 Hz, 1H), 7.67 (q, J=8.0 Hz, 2H), 7.32-7.21 (m, 6H), 7.15-7.11 (m, 1H), 6.86 (d, J=8.0 Hz, 2H), 6.18 (s, 1H), 4.54 (s, 2H), 3.49 (s, 3H), 3.22 (m, 1H), 2.25 (s, 3H), 1.36 (s, 3H), 1.34 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 144.0, 137.7, 137.2, 136.5, 134.1, 129.23, 129.17, 127.6, 127.4, 126.9, 126.6, 124.0, 123.0, 121.8, 120.6, 119.2, 119.1, 115.7, 112.8, 109.2, 32.7, 26.3, 22.5, 21.9, 21.7. IR (neat) ν 2969, 2936, 2875, 1722, 1679, 1612. HRMS (ESI) m/z calcd for C<sub>28</sub>H<sub>28</sub>N<sub>2</sub>O<sub>2</sub>S (M+Na)<sup>+</sup> 479.1764, found 479.1770.



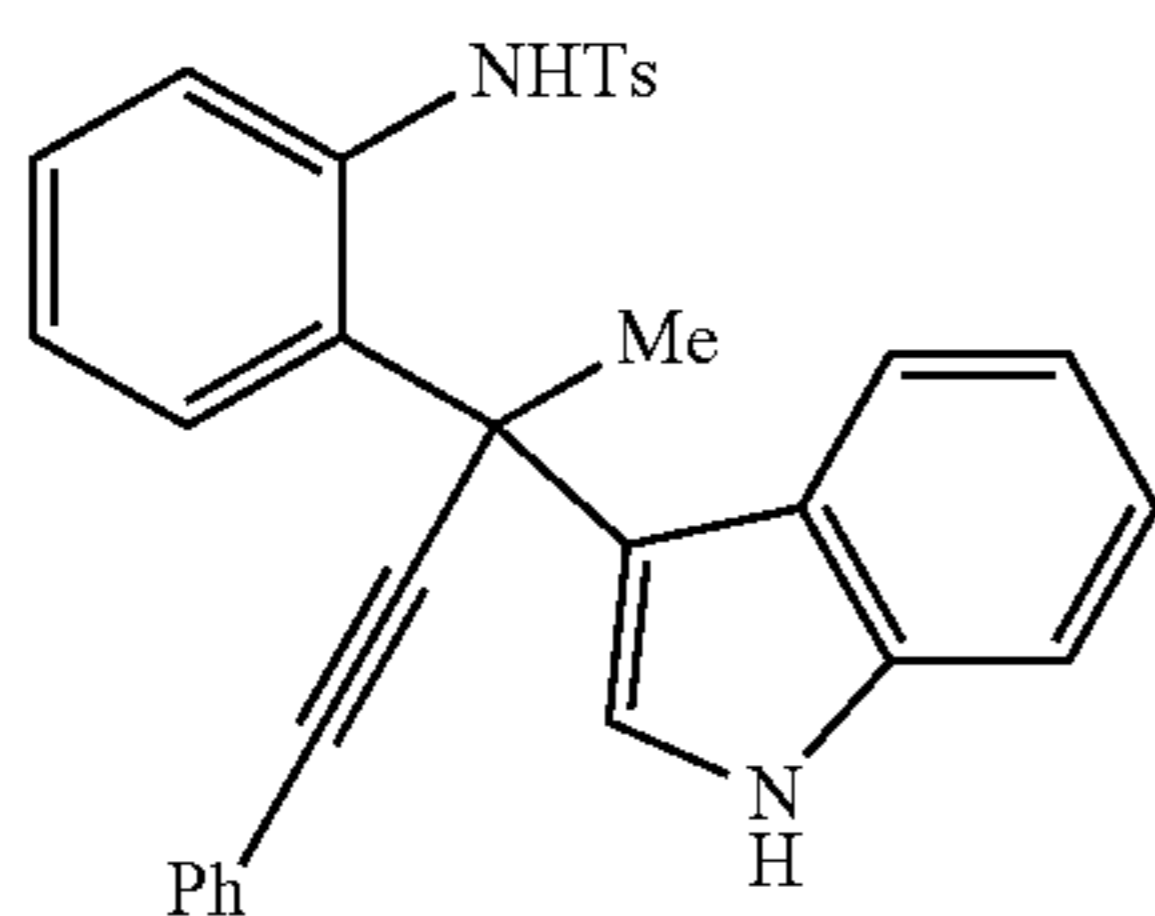
Compound 12c was isolated as colorless oil (21 mg, 42%). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 8.29 (d, J=10.0 Hz, 1H), 7.48 (d, J=5.0 Hz, 2H), 7.44-7.17 (m, 11H), 7.02 (m, 1H), 6.91 (d, J=5.0 Hz, 2H), 6.46 (s, 1H), 4.55 (s, 2H), 3.52 (s, 3H), 2.28 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ 144.2, 137.2, 137.0, 136.4, 133.4, 130.3, 130.0, 129.3, 128.9, 127.9, 127.8, 127.6, 127.4, 126.5, 124.8, 123.8, 123.7, 121.7, 119.9, 119.3, 119.1, 115.4, 113.0, 109.1, 32.7, 22.7, 21.8. IR (neat) ν 3764, 2923, 1738, 1711, 1530, 1513. HRMS (ESI) m/z calcd for C<sub>31</sub>H<sub>26</sub>N<sub>2</sub>O<sub>2</sub>S (M+Na)<sup>+</sup> 513.1607, found 513.1609.



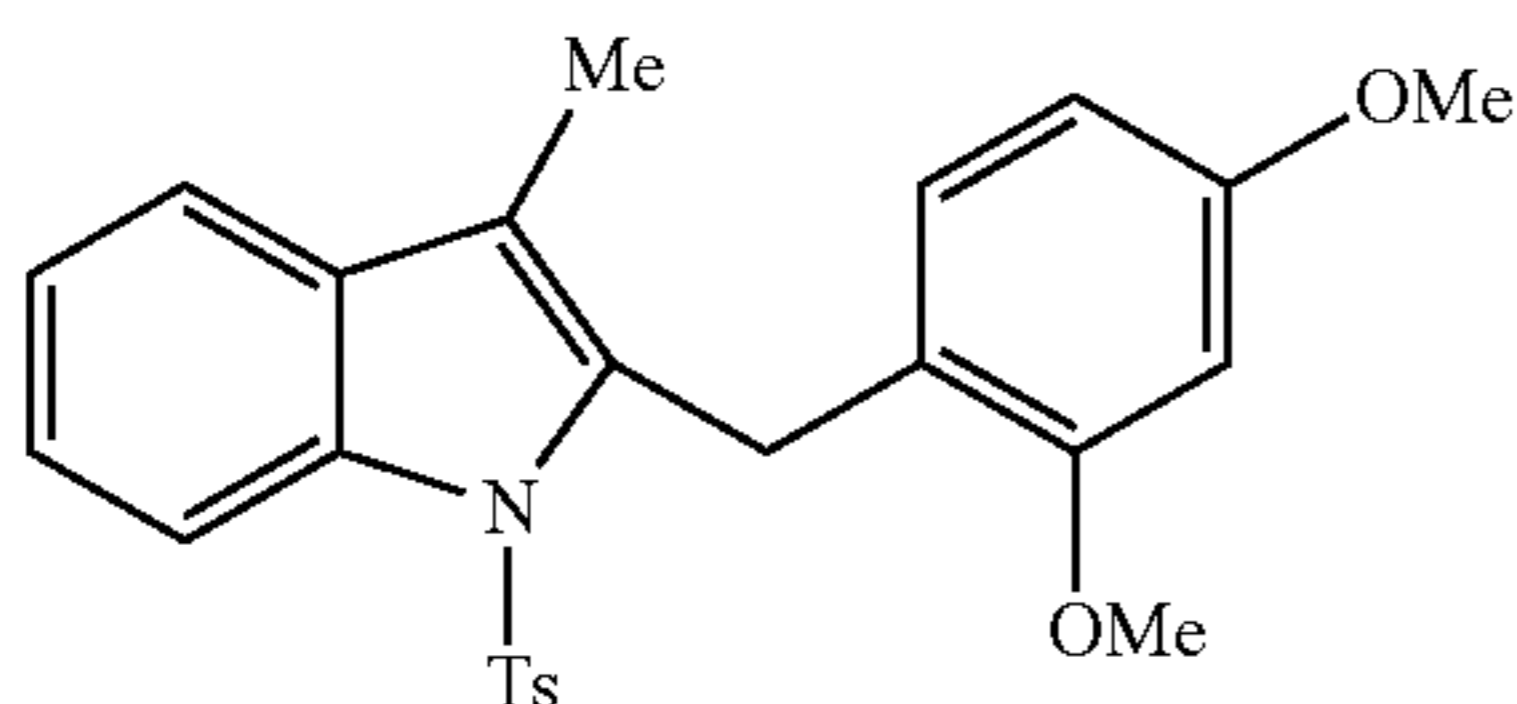
Compound 12d was isolated as brown oil (29 mg, 60%). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS): δ 8.31 (d, J=10.0 Hz, 1H), 7.94 (d, J=10.0 Hz, 1H), 7.56-7.53 (m, 2H), 7.38-7.29 (m, 4H), 7.23-7.21 (m, 2H), 7.11-7.08 (m, 1H), 6.87 (d, J=10.0 Hz, 2H), 6.48-6.43 (m, 2H), 6.38 (s, 1H), 4.74 (s, 2H), 3.51 (s, 3H), 2.24 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ 148.4, 144.4, 142.3, 137.1, 137.0, 136.9, 136.3, 129.4, 128.3, 127.72, 127.70, 126.6, 125.0, 124.1, 121.8, 120.9, 119.3, 119.2, 115.3, 114.0, 111.7, 111.5, 109.2, 108.8,

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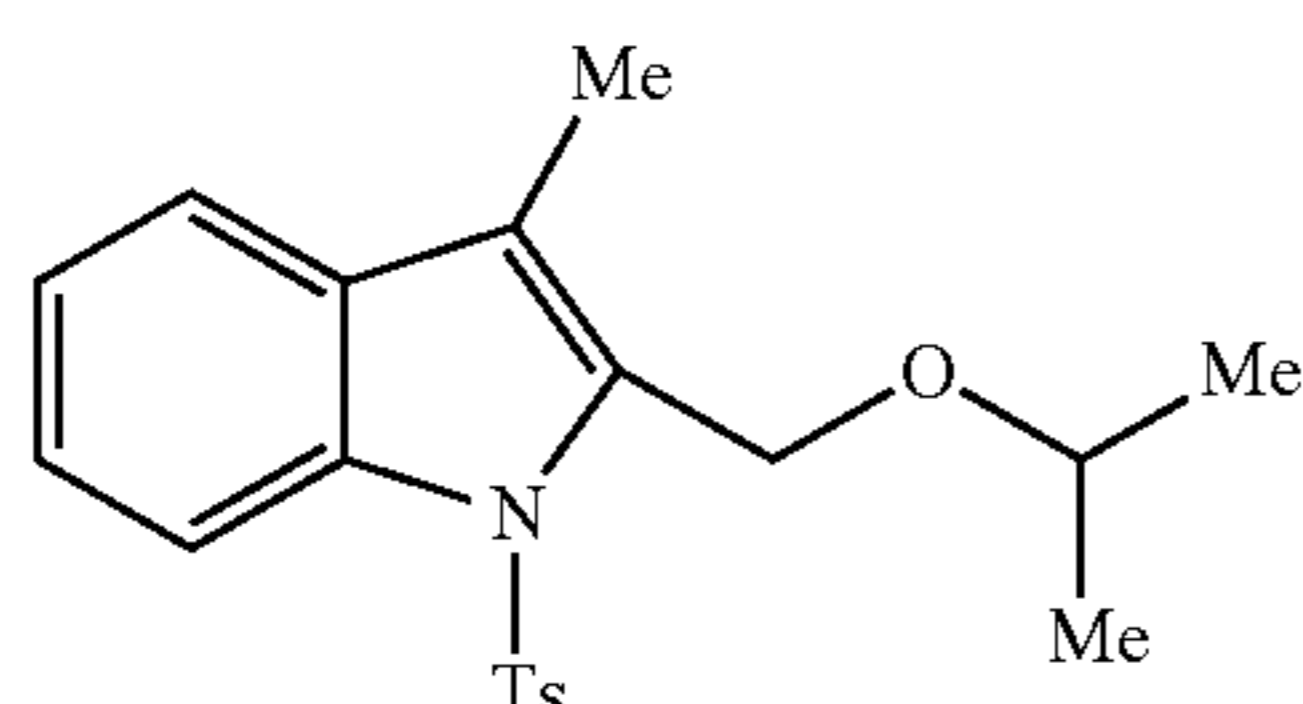
32.7, 23.2, 21.7. IR (neat)  $\nu$  3763, 2947, 1739, 1692, 1642, 1550. HRMS (ESI)  $m/z$  calcd for  $C_{31}H_{24}N_2O_2S$  (M+Na)<sup>+</sup> 503.1400, found 503.1400.



Compound 13 was isolated as white solid (30 mg, 63%). mp=161-163° C. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  8.27 (s, 1H), 7.98 (s, 1H), 7.73 (d, J=10.0 Hz, 1H), 7.50-7.48 (m, 2H), 7.44 (d, J=2.5 Hz, 1H), 7.38-7.36 (m, 2H), 7.32-7.30 (m, 3H), 7.19-7.14 (m, 2H), 7.10-7.06 (m, 3H), 7.03 (d, J=5.0 Hz, 1H), 6.88-6.85 (m, 1H), 6.80 (d, J=10.0 Hz, 2H), 2.23 (s, 3H), 2.12 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>):  $\delta$  143.5, 137.7, 136.4, 132.1, 131.3, 129.5, 128.62, 128.60, 128.55, 127.5, 127.3, 125.0, 123.5, 123.1, 122.8, 122.2, 120.6, 120.1, 120.0, 118.4, 111.9, 92.8, 85.0, 38.1, 29.6, 21.7. IR (neat)  $\nu$  2929, 2820, 1726, 1550. HRMS (ESI)  $m/z$  calcd for  $C_{31}H_{26}N_2O_2S$  (M+Na)<sup>+</sup> 513.1607, found 513.1609. X-ray structure (CCDC 1016688).



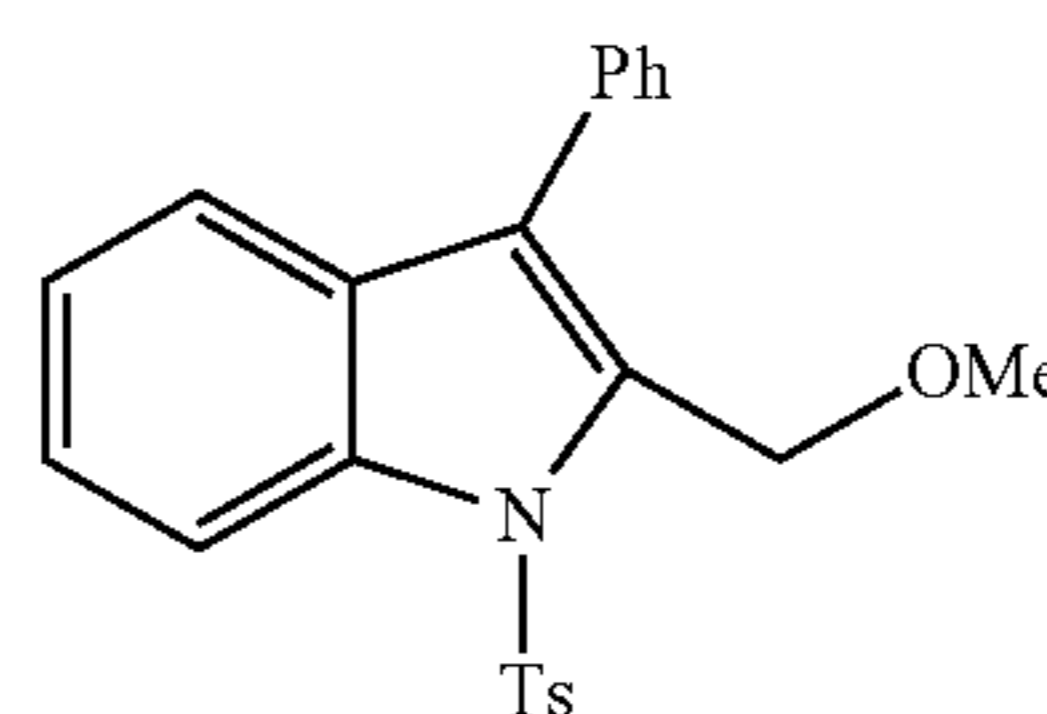
Compound 14 was isolated as colorless oil (14 mg, 64%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  8.23 (d, J=8.0 Hz, 1H), 7.47 (d, J=8.0 Hz, 2H), 7.43 (d, J=8.0 Hz, 1H), 7.33-7.24 (m, 2H), 7.04 (d, J=8.0 Hz, 2H), 6.51 (d, J=8.0 Hz, 1H), 6.46 (d, J=4.0 Hz, 1H), 6.18 (dd, J=8.0, 4.0 Hz, 1H), 4.32 (s, 2H), 3.88 (s, 3H), 3.75 (s, 3H), 2.28 (s, 3H), 2.11 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>):  $\delta$  159.5, 158.0, 144.4, 137.0, 136.4, 134.7, 131.5, 129.7, 129.0, 126.7, 124.4, 123.5, 119.9, 118.7, 115.4, 110.0, 104.0, 98.6, 55.8, 55.6, 25.1, 21.8, 9.2. IR (neat)  $\nu$  3763, 2941, 2839, 1613, 1589, 1505. HRMS (ESI)  $m/z$  calcd for  $C_{25}H_{25}NO_4S$  (M+Na)<sup>+</sup> 458.1397, found 458.1396.



Compound 15 was isolated as colorless oil (17 mg, 48%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  8.09 (d, J=8.0 Hz, 1H), 7.88 (d, J=8.0 Hz, 2H), 7.43 (d, J=8.0 Hz, 1H), 7.31-7.27 (m, 1H), 7.24-7.20 (m, 1H), 7.15 (d, J=8.0 Hz, 2H), 4.86 (s, 2H), 3.82 (m, 1H), 2.31 (s, 3H), 2.27 (s, 3H),

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1.24 (s, 3H), 1.22 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>):  $\delta$  144.5, 136.5, 133.4, 130.8, 129.7, 127.4, 125.3, 123.4, 120.3, 119.4, 115.1, 71.8, 60.0, 22.3, 21.8, 9.3. IR (neat)  $\nu$  2941, 2839, 1613, 1589, 1505. HRMS (ESI)  $m/z$  calcd for  $C_{20}H_{23}NO_3S$  (M+Na)<sup>+</sup> 380.1291, found 380.1292.



Compound 16 was isolated as colorless oil (24 mg, 62%). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>, TMS):  $\delta$  8.20 (d, J=10.0 Hz, 1H), 7.96 (d, J=10.0 Hz, 2H), 7.50-7.45 (m, 5H), 7.42-7.39 (m, 1H), 7.37-7.33 (m, 1H), 7.23-7.19 (m, 3H), 4.73 (s, 2H), 3.36 (s, 3H), 2.33 (s, 3H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>):  $\delta$  144.8, 136.5, 136.4, 133.1, 132.7, 130.4, 129.8, 129.3, 128.9, 128.1, 127.5, 126.7, 125.7, 123.8, 120.6, 115.1, 64.6, 58.1, 21.8. The spectra of compound 16 are in accordance with literature. Kothandaraman, P.; Rao, W.; Foo, S. J.; Chan, P. W. H. *Angew. Chem. Int. Ed.* 2010, 49, 4619.

#### 6. Biological Activity:

Glucagon-like peptide 1 (GLP-1) is derived from transcription of the proglucagon gene followed by posttranslational modifications of proglucagon to the following biologically active peptides: GLP-1 {7-37} and GLP-1 (7-36) NH<sub>2</sub>. GLP-1 secretion by ileal L cells is dependent on the presence of nutrients in the lumen of the small intestine. GLP-1 is a potent anti-hyperglycemic hormone inducing glucose-dependent insulin secretion and suppressing glucagon secretion. The glucose dependency of this mechanism is particularly important because GLP-1 does not stimulate insulin secretion and cause hypoglycemia when plasma glucose concentrations are in the normal fasting range.

The GLP-1 secretion assay identifies compounds that stimulate secretion of glucagonlikepeptide one (GLP-1) in mouse and human cell lines derived from gastrointestinal tract tissue. GLP-1 secretion is measured using an ELISA designed to detect the appropriate forms of GLP-1 secreted from these cells. If active in the cell-based GLP-1 assay, molecules can be further tested for selectivity in assays that measure activation of G-protein-coupled receptors (GPCRs) known to stimulate GLP-1 secretion. See, for example, "Glucagon-Like Peptide 1-Based Therapies for Type 2 Diabetes: A Focus on Exenatide," Kathleen Dungan and John B. Buse; *Clinical Diabetes* 29 (1), (Winter 2011); and "Glucagon-Like Peptide 1 Secretion by the L-Cell," Gareth E. Kim and Patricia L. Brubaker; *Diabetes*: 55 (supplement 2), (December, 2006).

Proprotein convertase subtilisin kexin type 9 (PCSK9) belongs to the proteinase K subfamily of secretory proteases. This protein plays a major regulatory role in cholesterol homeostasis. PCSK9 regulates plasma LDL-cholesterol (LDL-C) levels by directing LDL receptor (LDLR) to lysosomal degradation, resulting in reduced LDL clearance and accumulation of LDL in the circulation. Gain of function mutations of PCSK9 lead to hyperlipidemia and premature coronary artery disease (CAD) in humans, whereas loss of function mutations of PCSK9 are associated with lower levels of LDL and protection from CAD.

PCSK9 expression is actively regulated at transcription levels. Statins are known to stimulate PCSK9 transcription

which in turn curbs the efficacy of statins in LDL lowering in humans. A few other molecules including berberine and oncostatin have been shown to suppress PCSK9 transcription which in turn contributes to the hypolipidemic effects of these agents. The PCSK9 SI phenotypic assay is designed to identify compounds that inhibit synthesis of PCSK9 in human hepatoma cell lines (HepG2). See, for example, Horton, J. D., Cohen, J. C., and Hobbs, H. H., "PCSK9: a convertase that coordinates LDL catabolism," *J. Lipid Res.* 50 Suppl, S172-177, (2009); Crunkhorn, S. "Trial watch: PCSK9 antibody reduces LDL cholesterol," *Nat Rev Drug Discov* 11, 11, (2012); Vogel, R. A., "PCSK9 inhibition: the next statin," *J Am Coll Cardiol* 59, 2354-2355, (2012); Li, H., Dong, B., Park, S. W., Lee, H. S., Chen, W., and Liu, J., "Hepatocyte nuclear factor 1alpha plays a critical role in PCSK9 gene transcription and regulation by the natural hypocholesterolemic compound berberine," *J Biol Chem* 284, 28885-28895, (2009); and Cao, A., Wu, M., Li, H., and Liu, J., "Janus Kinase activation by cytokine oncostatin M decreases PCSK9 expression in liver cells," *J Lipid Res* 52, 518-530, (2011).

The IL-17 pathway plays an essential pathological role in many autoimmune diseases including arthritis, multiple sclerosis, psoriasis, and inflammatory bowel disease. IL-17 is produced and secreted by at least two classes of lymphocytes,  $\delta\gamma$  and CD4+ T cells (Th17). The orphan nuclear receptor ROR $\gamma$  is required for the differentiation of Th17 cells where over-expression in human and rodent T cells induces transcripts found in Th17 cells encoding key cytokines for the IL23 receptor and chemokines for the CCR6 receptor. In addition to ROR $\gamma$ , recent global analysis of transcription factors has highlighted the molecular complexity of the Th17 differentiation program.

The IL-17 phenotypic assay seeks to identify inhibitors of IL-17 secretion from human peripheral blood mononuclear cells (PBMCs) following stimulation of memory T cells by IL-23, anti-CD3, and anti-CD28. Compounds of interest will inhibit IL-17. See W. Ouyang, J. K. Kolls, V. Zheng, "The biological functions of T helper 17 cell effector cytokines in inflammation," *Immunity*, 28, 454-467 (2008); I. I. Ivanov, L. Zhou, D. R. Littman, "Transcriptional regulation of Th17 cell differentiation," *Semin Immunol*, 19, 409-417 (2007); N. Mane I, D. Unutmaz, D. R. Littman, "The differentiation of human T(H)-17 cells requires transforming growth factor-beta and induction of the nuclear receptor ROR $\gamma$ ," *Nat Immunol*, 9, 641-649 (2008); and M. Ciofani, A. Madar, C. Galan, M. Sellars, K. Mace, F. Pauli, A. Agarwal, W. Huang, C. N. Parkurst, M. Muratet, K. M. Newberry, S. Meadows, A. Greenfield, V. Vang, P. Jain, F. K. Kirigin, C. Birchmeier, E. F. Wagner, K. M. Murphy, R. M. Myers, R. Bonneau, D. R. Littman, "A validated regulatory network for Th17 cell specification." *Cell*, 151, 289-303 (2012).

#### (6.1) GLP-1 mSTC Assay:

##### (6.1.1) Materials:

The mouse enteroendocrine-like STC-1 cell line is described in (*Am. J. Pathol.* 1990 June; 136(6):1349-63. Rindi G, Grant S G, Yiangou Y, Ghatei M A, Bloom S R, Bantich V L, Solcia E, Polak J M.). The GLP-1 peptide used as standards in the "AlphaLISA"<sup>®</sup>-brand assay ("AlphaLISA" is a registered trademark of PerkinElmer): 7-37 was purchased from Bachem, Inc., Redwood City, Calif., USA (catalog no. H67950). Bovine serum albumin was purchased from MP Biomedicals, LLC (Santa Ana, Calif., USA; catalog no. #15240). Plates for cell growth were purchased from Greiner Bio-One North America, Inc. (Monroe, N.C., USA) and the Proxi-plates plus for reading the AlphaLISA were from Perkin Elmer.

##### (6.1.2) Cell Culture Conditions:

STC-1 cells were grown adherently at 37° C. in a humidified incubator at 5% CO<sub>2</sub> using DMEM (with high glucose and L-glutamine; Hyclone, a division of GE Life Sciences; Logan, Utah, USA) containing 10% US Certified heat inactivated fetal bovine serum (Invitrogen, a division of Thermo Fisher Scientific Inc., Grand Island, N.Y., USA), 10 mM HEPES (Invitrogen), and anti-biotic/anti mycotic (Invitrogen) for cell maintenance. For GLP-1 secretion experiments cells were plated at 12,000 per well in 80  $\mu$ l of media on poly-D-lysine 384 well plates black with clear bottom (Greiner).

##### (6.1.3) GLP-1 Secretion Studies:

On the day of the assay the cells are washed three times with 80  $\mu$ l/well HBSS plus 0.1% BSA using a plate washer (BioTech). 50  $\mu$ l per well HBSS plus 0.1% BSA is added to cells and then 100  $\mu$ l of compound is dispensed onto cells (PinTool, V&P Scientific, Inc., San Diego, Calif., USA). Cells were treated with compound at a starting concentration of 40  $\mu$ M with a 2-fold serial dilution for a dose response. Cells were incubated with compound for 2 hours at 37° C. GLP-1 in supernatants was quantified using a homogenous "AlphaLISA"<sup>®</sup>-brand assay in a 384-well format. Samples were read on an Envision photometer (Perkin Elmer) and the assay was calibrated to synthetic GLP-1 peptide.

##### (6.1.4) Data Processing and Statistical Analysis:

For single point activity the % stimulation is calculated based on normalizing the GLP-1 secreted to a compound which produces a robust and reproducible response of GLP-1 secretion in the mSTC cells.

Percent stimulation and percent inhibition were calculated by Equation 1 and Equation 2, respectively, using the Maximum (Max) and Minimum (Min) response conditions for each assay.

$$\text{Stimulation (\%)} = \frac{\text{Signal} - \text{Min}}{\text{Max} - \text{Min}} * 100 \quad \text{Equation 1}$$

$$\text{Inhibition (\%)} = \left(1 - \frac{\text{Signal} - \text{Min}}{\text{Max} - \text{Min}}\right) * 100 \quad \text{Equation 2}$$

The EC<sub>50</sub> or IC<sub>50</sub> of test compounds was determined by fitting the calculated percent activation or inhibition values using a standard 4 parameter logistic and non-linear regression analysis.

#### (6.2) GLP-1 NCI Assay

##### (6.2.1) Materials:

NCI-H716 cells (ATCC, CCL-251) were obtained from the American Type Culture Collection (Manassas, Va., USA). Cells were grown at 37° C., in a humidified incubator at 5% CO<sub>2</sub> unless otherwise noted. Cell Culture reagents were purchased from either HyClone or Invitrogen. The GLP-1 peptides used as standards in the "AlphaLISA"<sup>®</sup>-brand assay; 7-36 and 7-37 were purchased from BACHEM (H9560 and H67950). BSA is purchased from MP (#15240). DPP-IV inhibitor was purchased from Millipore (Waltham, Mass., USA; catalog no. DDP4-010). Plates for cell growth were purchased from Greiner and the Proxi-plates plus for reading the "AlphaLISA"<sup>®</sup>-brand assay were from Perkin Elmer<sup>™</sup>.

##### (6.2.2) Cell Culture Conditions:

Human NCI-H716 cells were grown in suspension at 37° C., in a humidified incubator at 5% CO<sub>2</sub> in RPMI 1640 medium (Invitrogen) supplemented with 10% US Certified heat inactivated FBS (Invitrogen), 2 mM L-glutamine (Invitrogen), 10 mM HEPES (Hyclone) and Anti Biotic/Anti

Mycotic (Hyclone) for cell maintenance. The cells were then grown in a “differentiation” media prior to being tested for GLP-1 secretion. The “differentiation” media was comprised of DMED High Modified (Hi-gluocse, +L-glu, -Phe-  
nol Red), 10 mM HEPES, 10% US Certified heat inactivated  
FBS (HyClone), and Anti Biotic/Anti Mycotic (Hyclone).  
For GLP-1 secretion experiments cells were seeded on  
poly-D-lysine 384 well plates black with clear bottom  
(Greiner).

#### (6.2.3) GLP-1 Secretion Studies in NCI-H716 Cells:

Human NCI-H716 cells were grown in “differentiation”  
media prior to being used in the assay for GLP-1 secretion.  
On the day of the assay the cells are washed twice in HBSS  
plus 0.1% BSA plus 1% DPPIV Inhibitor and re-suspended  
in HBSS plus 0.1% BSA plus 1% DPP-IV Inhibitor. Cells  
were seeded at 10,000 cells per well in 384 well PD plates  
in 50 ul per well. Cells were treated with compound at a  
starting concentration of 40 uM with a 3 fold serial dilution  
for a dose response. Cells were incubated with compound  
for 2 hours at 37° C. GLP-1 in supernatants was quantified  
using a homogenous “AlphaLISA”®-brand assay in a 384-  
well format. Samples were read on an Envision (Perkin  
Elmer and the assay was calibrated to synthetic GLP-1  
peptides.

#### (6.2.4) Data Processing and Statistical Analysis:

For single point activity the % stimulation is calculated  
based on normalizing the GLP-1 secreted to a compound  
which produces a maximum response of GLP-1 secretion in  
the NCI cells.

Percent stimulation and percent inhibition were calculated  
by Equation 1 and Equation 2, respectively, using the  
Maximum (Max) and Minimum (Min) response conditions  
for each assay (Supplementary Information).

$$\text{Stimulation (\%)} = \frac{\text{Signal} - \text{Min}}{\text{Max} - \text{Min}} * 100 \quad \text{Equation 1}$$

$$\text{Inhibition (\%)} = \left(1 - \frac{\text{Signal} - \text{Min}}{\text{Max} - \text{Min}}\right) * 100 \quad \text{Equation 2}$$

The EC50 or IC50 of test compounds was determined by  
fitting the calculated percent activation or inhibition values  
using a standard 4 parameter logistic and non-linear regres-  
sion analysis.

#### (6.3) PCSK9 Inhibition Assay:

Inhibition of secreted PCSK9 was measured in human  
hepatocellular carcinoma (HepG2) cells using an  
“AlphaLISA”®-brand assay. Given that this assay is run in  
an inhibition mode, the viability of cells was also assessed  
to rule out compounds whose PCSK9 inhibition resulted  
from deleterious effects on cell health. Freshly cultured  
HepG2 cells were harvested from poly-d-lysine-coated T225  
cell culture flasks and plated in biocoat poly-d-lysine coated  
384 black with clear bottom microtiter plates (BD BioCoat  
#356663; Becton, Dickinson and Company, Franklin Lakes,  
N.J., USA) at 20,000 cells/well in 60 ul of growth media  
(MEM+10% heat inactivated FBS+1% NEAA+1% sodium  
pyruvate+1% GlutaMAX). Cell plates were incubated over-  
night at 37° C. and 5% CO<sub>2</sub> prior to compound treatment.

Compounds were serially diluted 3-fold in 100% DMSO  
to achieve a starting final assay plate concentration of 50 uM  
following a 20-fold dilution in assay media (MEM+5% heat  
inactivated FBS+1% NEAA+1% sodium pyruvate+1% Glu-  
taMAX) and a 10-fold dilution into the cell plates. While the  
compounds were diluting, the cell plates were washed twice  
with 75 ul of assay media and refilled with 45 ul of assay

media. The cell plates were incubated for 48 hrs at 37° C.  
and 5% CO<sub>2</sub> prior to running the “AlphaLISA”®-brand  
assay. The “AlphaLISA”® bead mix was assembled in water  
and left to incubate 1 hr in the dark prior to use (1x  
“AlphaLISA”® buffer, 5 mg/ml mAb-PCSK9-A4 conju-  
gated acceptor beads, 3.4 uM bioti-mAb-anti-PCSK9-B9, 5  
mg/ml streptavidin-coated donor beads). Following the cell  
incubation, 15 ul of supernatant was transferred from the cell  
plates to 384 ProxiPlates. 15 ul of warm assay media was  
immediately added back to the cell plates. In the dark, 5 ul  
of the bead mix was added to the ProxiPlates, and then the  
plates were left to incubate at ambient temperature in the  
dark overnight before being read on an Envision (excitation  
680 nm and emission 615 nm). 10 ul of stain (serum-free  
MEM, Hoechst stain, propidium iodide) was added to the  
cell plates followed by an incubation at 37° C. and 5% CO<sub>2</sub>  
for 3 hours. The plates were removed from the incubator,  
sealed with black tape, and read for propidium iodide stained  
nuclei using an Acumen-brand cell imaging system (TTP  
Labtech Ltd., Melbourn, Hertfordshire United Kingdom).  
Percent inhibitions at all concentrations tested were calcu-  
lated relative to 0.5% DMSO (min effect), and the effect of  
50 uM of a fully efficacious PCSK9 inhibitor for the PCSK9  
inhibition assay (max effect), or 50 uM Brefeldin A for the  
viability assay (max effect). IC50 values were calculated  
using a 4 parameter logistic curve fitting equation.

In order to rule out compounds that nonspecifically inhibit  
secretion of proteins, a Metridia luciferase (24 kDa protein  
containing an N-terminal secretory signal peptide) assay was  
conducted in HepG2 cells. Freshly cultured HepG2 cells  
stably transfected with Metridia luciferase were harvested  
from poly-d-lysine coated T225 cell culture flasks and plated  
in 384 well, black, clear bottom, poly-d-lysine coated plates  
at 20,000 cells/well in 60 ul of assay media (MEM+10%  
heat inactivated FBS+2% NEAA+2% sodium pyruvate+1%  
GlutaMAX+2% penicillin streptomycin+2% G418). The  
compounds of interest were dosed as previously described  
excluding the washing of cells.

The cell plates were incubated at 37° C. and 5% CO<sub>2</sub> for  
5 hours. Next, 15 ul of the supernatant was added to  
384-well Perkin Elmer Optiplates. The plates were then  
incubated at ambient temperature for 10 minutes and the  
luciferase signal was quantified on an Envision-brand pho-  
tometer (Perkin Elmer). Percent inhibitions at all concen-  
trations tested were calculated relative to 0.5% DMSO (min  
effect) and the effect of 50 uM Brefeldin A (max effect).  
IC50 values were calculated using a 4 parameter logistic  
curve fitting equation.

#### 7. Representative Procedure for the Formation of Diindolylmethane and Removing of Boc-Protecting Group:

To a vial under argon atmosphere containing propargyl  
ether 7 (0.38 mmol, 100 mg) in dioxane (0.2 M) was added  
5-chloroindole (0.76 mmol, 117 mg), platinum dichloride  
(10 mol %, 10 mg), and sodium bicarbonate (0.57 mmol, 61  
mg). The reaction was stirred at 100° C. overnight. The  
crude mixture was filtered and washed with ethyl acetate.  
The volatiles were removed under reduced pressure. The  
crude mixture was then heated to 160° C. for 2 h. The  
product was purified by flash column chromatography elut-  
ing with 5:1 hexanes/ethyl acetate to give an off-white solid  
10a (56 mg, 52% yield, m.p.=140-143° C.).

#### 8. Representative Procedure for the Formylation Reaction:

To a round bottom flask under argon atmosphere contain-  
ing N,N-dimethylformamide (0.2 M, 0.5 ml) at 0° C., was  
added phosphoryl chloride (0.12 mmol, 11 ul). The mixture  
was allowed to stir for 15 min. Diindolylmethane 10a (0.1  
mmol, 30 mg) was dissolved in minimal DMF and the



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solution was added dropwise to the reaction mixture at 0° C. the reaction was warmed to room temperature and allowed to stir for 6 h. The crude reaction mixture was poured into a separatory funnel containing saturated sodium bicarbonate solution. The products were extracted 4x with diethyl ether and washed with 0.1M sodium hydroxide. The organic phase was collected and all volatiles were removed under reduced pressure. The product was purified by flash column chromatography eluting with 3:1 hexanes/ethyl acetate to give a bright orange solid 11a (18 mg, 55% yield, m.p.=162-163° C.).

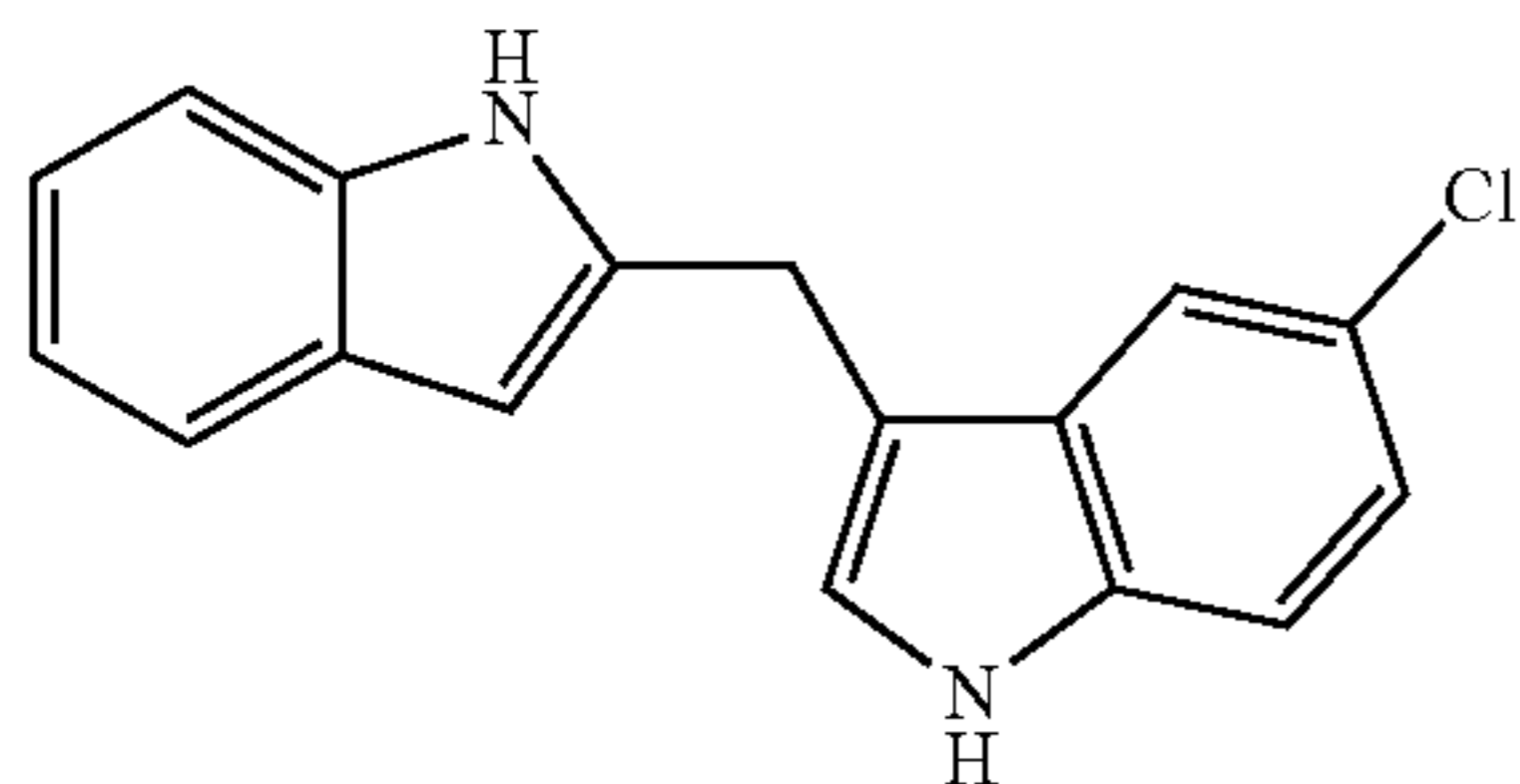
#### 9. Representative Procedure for the Biological Assay:

The human Hep G2 cell line from the Small Molecule Screening and Synthesis Facility (UWCCC, Madison, Wis.) and was maintained in DMEM medium supplemented with 10% FBS. Cells were incubated at 37° C. in a humidified atmosphere supplemented with 5% CO<sub>2</sub>.

Preparation of cells: Cells were cleaved from T75 flasks with 0.05% trypsin. The cells were then collected by spinning at 1 g for 4 min. Excess media containing trypsin was removed from the pellet, which was then re-suspended in growth media. The cells were then counted using a hemocytometer. Cells were plated in sterile 96-well clear bottom black culture plates at a density of 20,000 cells per well in 0.1 mL of media. The cells were then incubated for 24 h at 37° C. in a humidified atmosphere supplemented with 5% CO<sub>2</sub>.

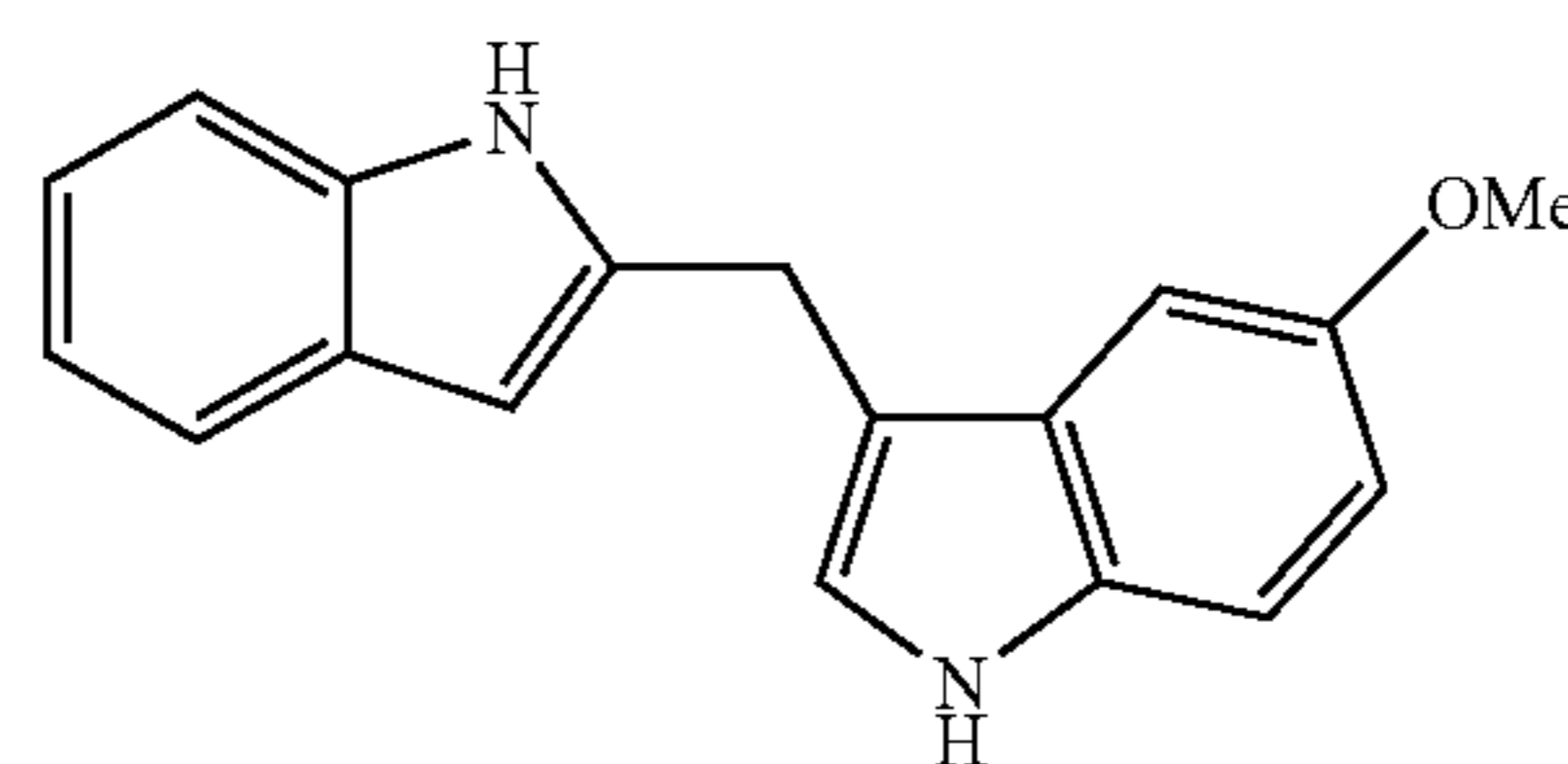
The ethoxyresorufin-O-deethylase (EROD) assay was performed on cell cultures of human Hep G2 cells. Briefly, 24 h after plating, cells in 96-well plates were treated with AhR agonists and allowed to incubate for 24 h. Each well was then rinsed with 200 uL of PBS buffer twice. To each well was then added 100 uL of 150 nM solution of 7-ethoxyresorufin and allowed to incubate for 2 h. Fluorescence measurements were obtained with a Safire II micro plate reader with excitation at 520 nm with a 25 nm bandwidth and emission at 595 nm with a 20 nm bandwidth.

#### 10. Characterization Data for New Compounds:



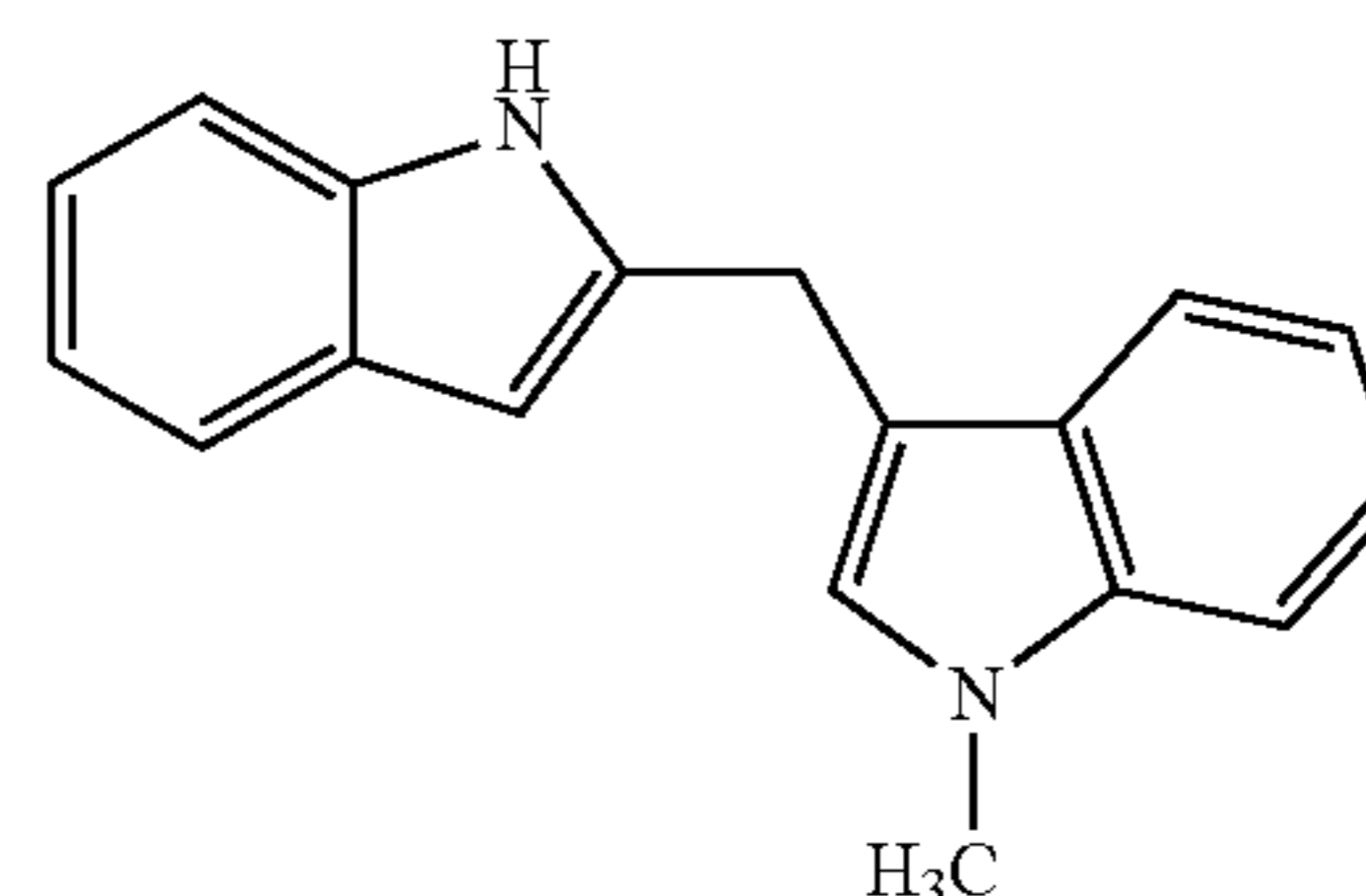
<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 4.23 (s, 2H), 6.37 (s, 1H), 7.04-7.12 (m, 3H), 7.16 (dd, J=8.4, 2 Hz, 1H), 7.21-7.24 (m, 1H), 7.29 (d, J=8.8 Hz, 1H), 7.51 (d, J=2 Hz, 1H), 7.53-7.56 (m, 1H), 7.83 (s, 1H), 8.04 (s, 1H); <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 137.85, 136.21, 134.96, 129.04, 128.59, 125.75, 124.16, 122.99, 121.38, 120.18, 119.90, 118.69, 113.01, 112.43, 110.67, 100.57, 24.58. IR (neat) 670.07, 734.21, 798.73, 1160.22, 1454.79, 1729.59, 2852.67, 3414.90 cm<sup>-1</sup>. HRMS (ESI) M/Z calcd. for C<sub>17</sub>H<sub>13</sub>ClN<sub>2</sub> (M+H)<sup>+</sup> 281.0841 found: 281.0841.

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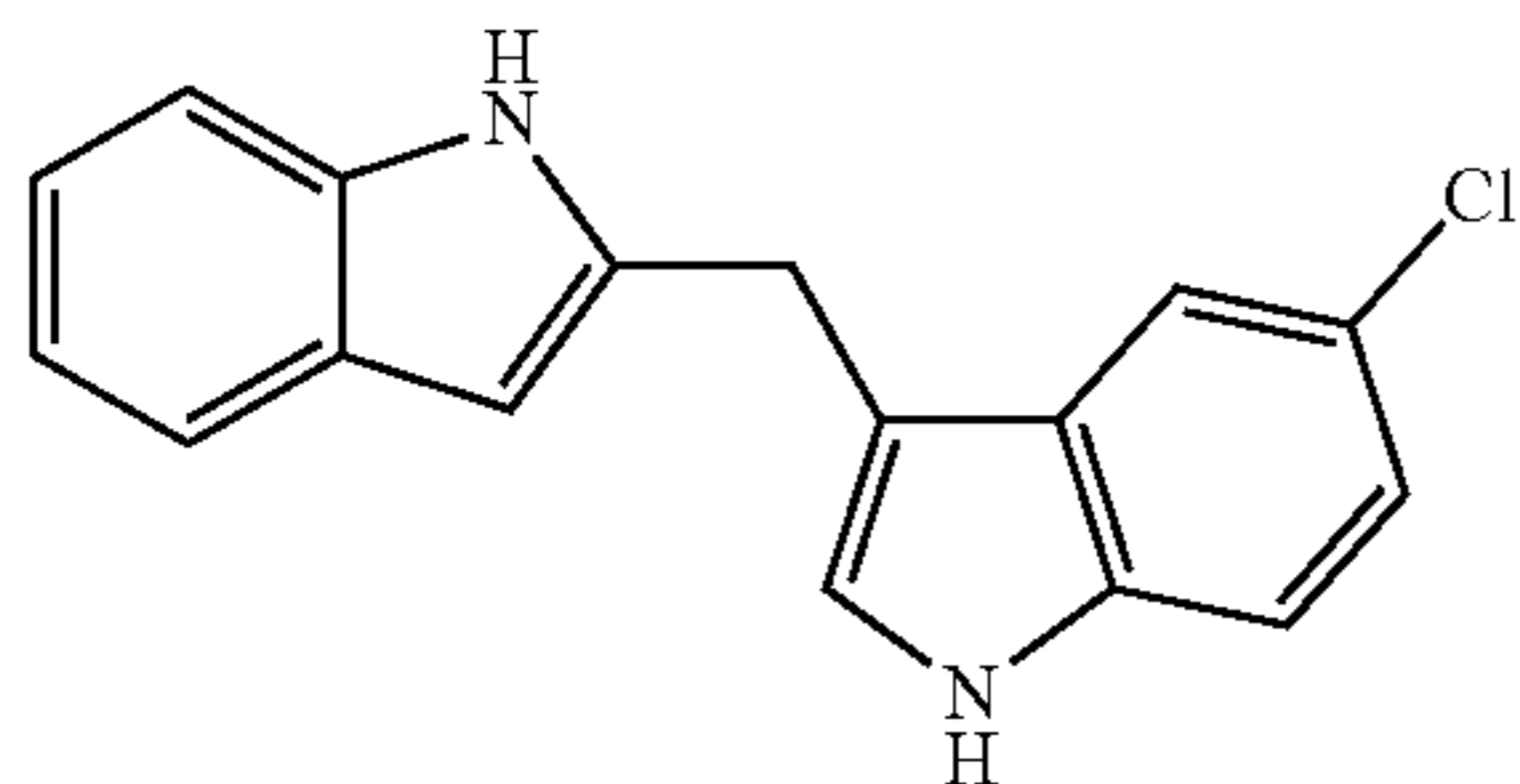
Pale yellow solid (m.p.=185-188° C.), 74 mg, 70% yield.

<sup>1</sup>H NMR (400 MHz, acetone): δ 3.68 (s, 3H), 4.21 (s, 2H), 6.24 (s, 1H), 6.72 (dd, J=8.8, 2.4 Hz, 1H), 6.87-6.97 (m, 2H), 6.99 (d, J=2.4 Hz, 1H), 7.14 (s, 1H), 7.22-7.28 (m, 2H) 7.40 (d, J=8.8, 1H), 9.89 (s, 2H) <sup>13</sup>C NMR (100 MHz, acetone): δ 153.97, 139.58, 136.86, 132.21, 129.26, 128.12, 124.00, 120.40, 119.51, 118.95, 112.43, 112.05, 111.60, 110.74, 100.79, 99.54, 55.12, 24.40. δ IR (acetone) 747.49, 790.29, 890.19, 1025.00, 1168.98, 1214.05, 1455.68, 1694.21, 2360.77, 3397.12 v cm<sup>-1</sup>. HRMS (ESI) M/Z calcd. for C<sub>18</sub>H<sub>16</sub>N<sub>2</sub>O (M+H)<sup>+</sup> 277.1336 found: 277.1324.



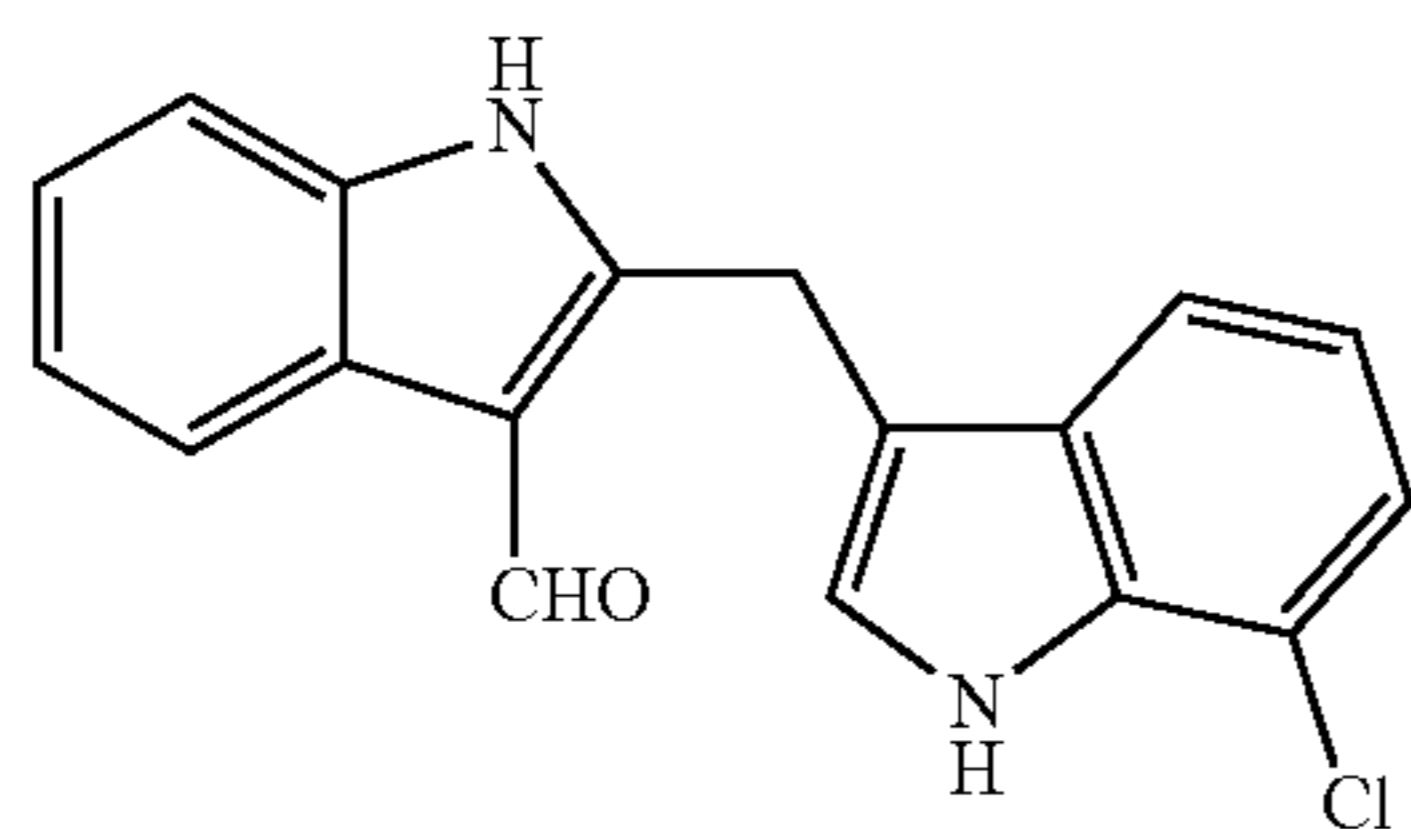
Orange oil, 65 mg, 67% yield.

<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 3.74 (s, 3H), 4.26 (s, 2H), 6.38 (s, 1H), 6.91 (s, 1H), 7.04-7.09 (m, 3H), 7.15-7.18 (m, 1H) 7.21-7.25 (m, 1H), 7.33 (d, J=8.00 Hz, 1H), 7.49-7.55 (m, 2H) 7.83 (s, 1H); <sup>13</sup>C NMR (CDCl<sub>3</sub>, 100 MHz): δ 138.59, 137.32, 136.05, 129.03, 127.83, 127.56, 122.02, 121.07, 119.97, 119.68, 119.33, 119.20, 111.31, 110.59, 109.43, 100.10, 32.82, 24.51. IR (neat) 737.42, 779.57, 908.07, 1011.12 1292.42, 1372.54, 1472.64, 3400.12 cm<sup>-1</sup>.



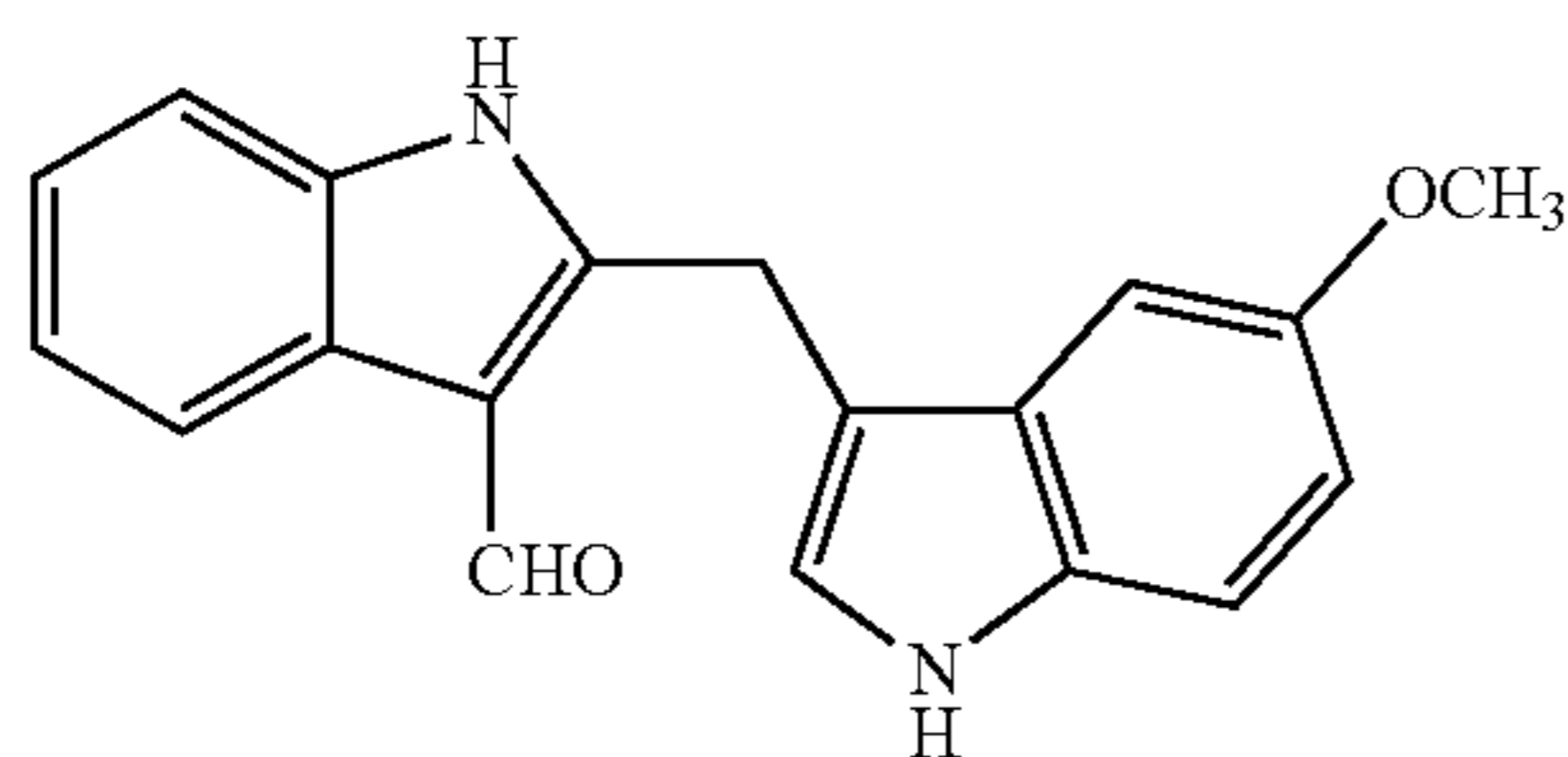
<sup>1</sup>H NMR (400 MHz, d<sub>6</sub>-acetone): δ 4.74 (s, 2H), 7.13-7.18 (m, 1H), 7.18-7.23 (m, 2H), 7.32-7.39 (m, 2H), 7.49 (s, 1H), 7.71 (s, 1H), 8.23 (s, 1H), 9.27 (s, 1H), 10.42 (s, 1H), 11.02 (s, 1H). <sup>13</sup>C NMR (100 MHz, d<sub>6</sub>-acetone) δ 184.06, 150.03, 135.96, 131.96, 129.31, 125.39, 123.51, 123.02, 122.18, 121.36, 120.80, 120.28, 117.75, 116.59, 114.16, 112.42, 111.58, 22.31. IR (neat) 747.35, 795.21, 1227.57, 1382.07, 1634.18, 1706.07, 2360.11, 2921.17, 3260.71 cm<sup>-1</sup>. HRMS (ESI) M/Z calcd. for C<sub>18</sub>H<sub>13</sub>ClN<sub>2</sub>O (M+H)<sup>+</sup> 309.0790, found: 309.0783.

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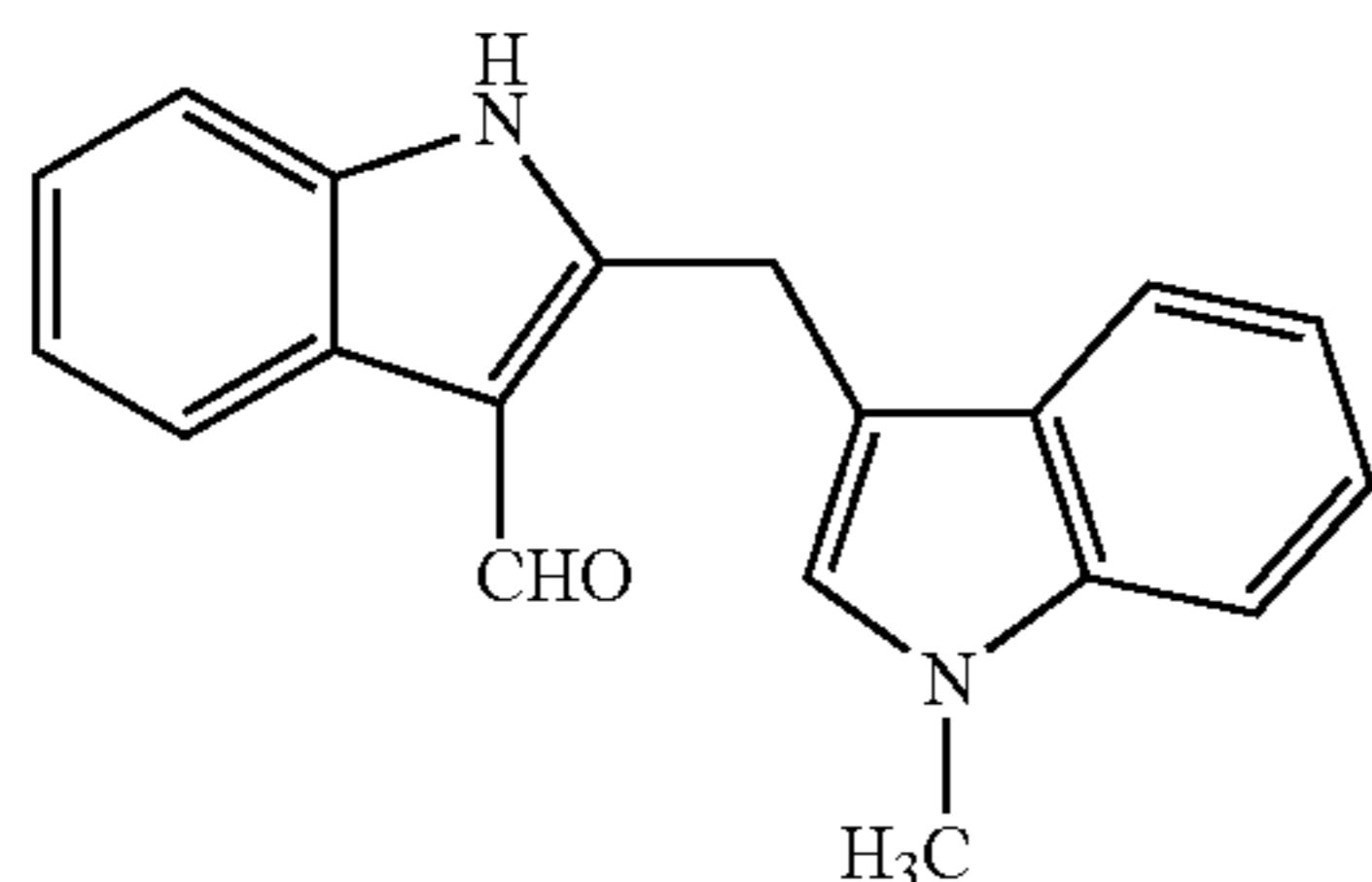
Pale orange solid, m.p.=170-172° C., 19 mg, 52% yield.

<sup>1</sup>H NMR (400 MHz, d<sub>6</sub>-acetone): δ 4.73 (s, 2H), 7.00 (t, J=7.6 Hz, 1H), 7.13-7.20 (m, 3H), 7.30-7.34 (m, 1H), 7.45 (s, 1H), 7.49 (d, J=8.0 Hz, 1H) 8.21 (d, J=6.4 Hz, 1H), 10.42 (s, 1H), 10.55 (s, 1H), 10.85 (s, 1H) <sup>13</sup>C NMR (CDCl<sub>3</sub>, 100 MHz): δ 184.59, 148.48, 134.92, 134.03, 128.50, 126.69, 124.25, 123.64, 123.05, 122.47, 121.37, 120.87, 117.56, 117.27, 114.24, 111.52, 111.23, 23.13. IR (neat) 731.76, 907.67, 1382.91, 1457.99, 1635.54, 2925.03, 3265.54 cm<sup>-1</sup>. HRMS (ESI) M/Z calcd. for C<sub>18</sub>H<sub>13</sub>ClN<sub>2</sub>O (M+H)<sup>+</sup> 309.0790, found: 309.0789.



Pale yellow solid, decomposed at 183° C., 15 mg, 53% yield.

<sup>1</sup>H NMR (400 MHz, d<sub>6</sub>-acetone): 3.65 (s, 3H), 4.57 (s, 2H), 6.87 (d, J=8.6, 1H), 7.03-7.11 (m, 3H), 7.230 (d, J=7.5 Hz, 1H), 7.47 (s, 1H), 8.08 (s, 2H), 9.05 (s, 1H), 10.27 (s, 1H), 10.88 (s, 1H); <sup>13</sup>C NMR (100 MHz, d<sub>6</sub>-acetone) δ 184.15, 154.26, 132.18, 124.63, 124.47, 123.25, 122.94, 122.31, 122.12, 120.81, 113.51, 112.34, 112.29, 111.97, 111.67, 111.57, 100.45, 55.28, 22.32. IR (neat) 748.59, 1228.73, 1365.64, 1466.37, 1642.24, 1708.78, 2360.38, 3003.91, 3423.55 cm<sup>-1</sup>. HRMS (ESI) M/Z calcd. for C<sub>19</sub>H<sub>16</sub>N<sub>2</sub>O<sub>2</sub> (M+H)<sup>+</sup> 305.1285, found: 305.1284.



Red solid, m.p.=130-131° C., 16 mg, 56% yield.

<sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ 3.82 (s, 3H), 4.66 (s, 2H), 7.04 (s, 1H), 7.12 (t, J=7.6 Hz, 1H), 7.17 (d, J=3.6 Hz, 2H), 7.31 (d, J=7.6 Hz, 1H) 7.38 (d, J=8 Hz, 2H), 7.47 (d, J=8.00 Hz, 1H), 8.25 (d, J=8, 1H) 8.33 (s, 1H), 10.41 (s, 1H); <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>) δ 184.69, 149.66, 137.56, 134.97, 128.42, 127.62, 126.78, 123.54, 123.01, 122.65, 121.02, 120.05, 119.01, 114.12, 111.27, 109.89, 108.54, 33.11, 22.91. IR (neat) 700.76, 749.62, 1222.43, 1399.13, 1465.59,

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1657.61, 1712.41, 2359.57, 2821.52, 3360.22 cm<sup>-1</sup>. HRMS (ESI) M/Z calcd. for C<sub>19</sub>H<sub>16</sub>N<sub>2</sub>O (M+H)<sup>+</sup> 289.1336, found: 289.1338.

11. Pharmacological Activity:

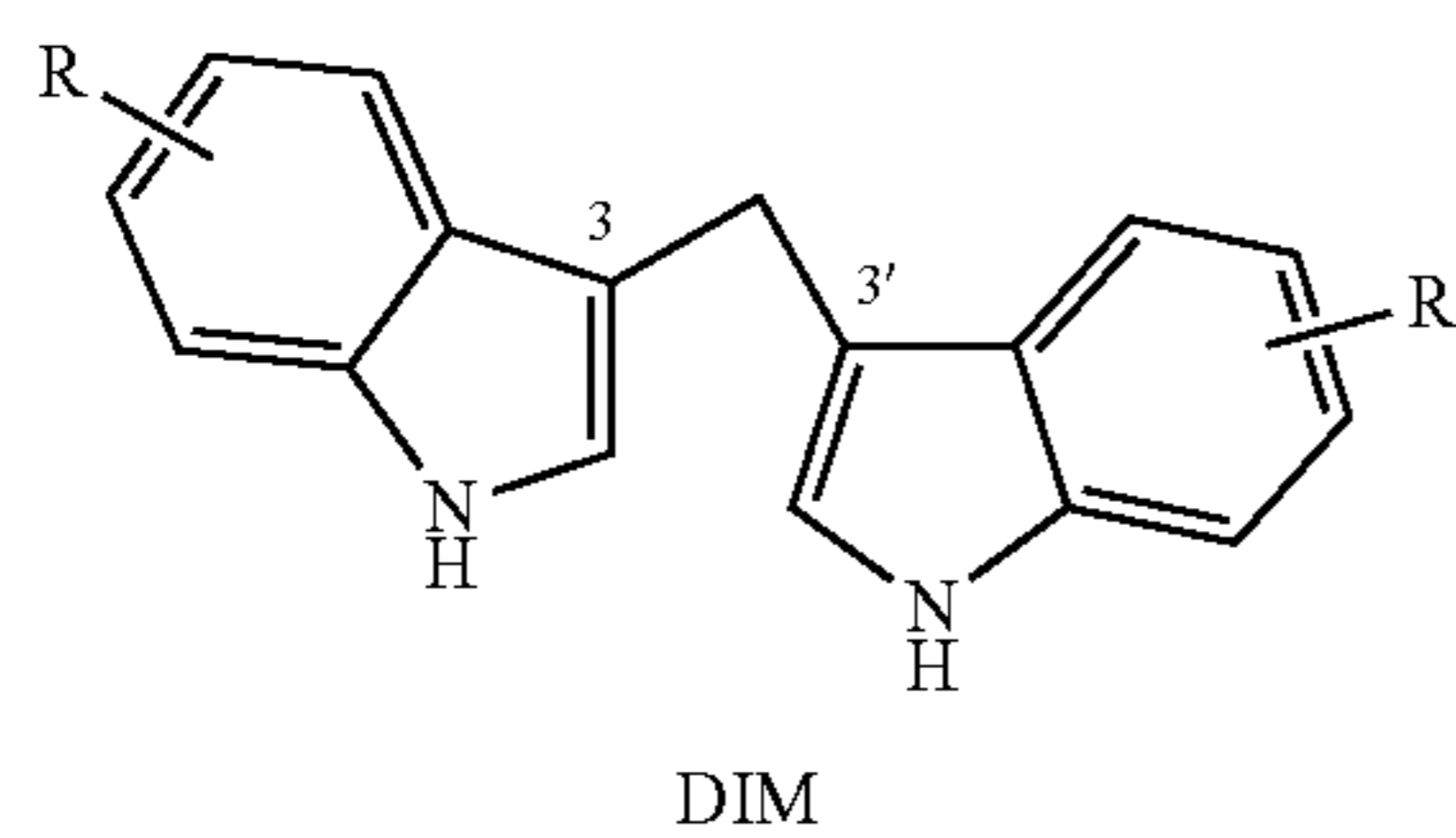
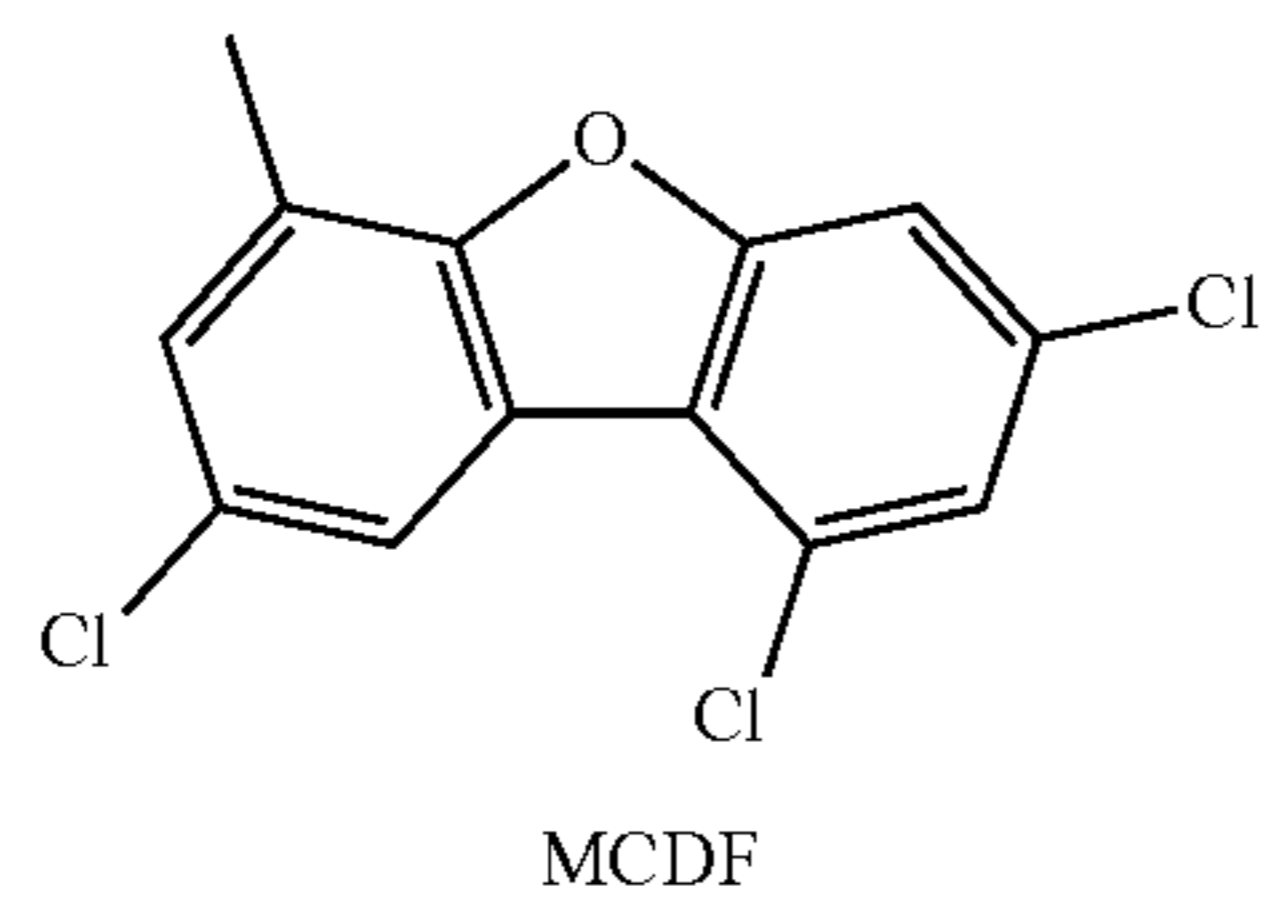
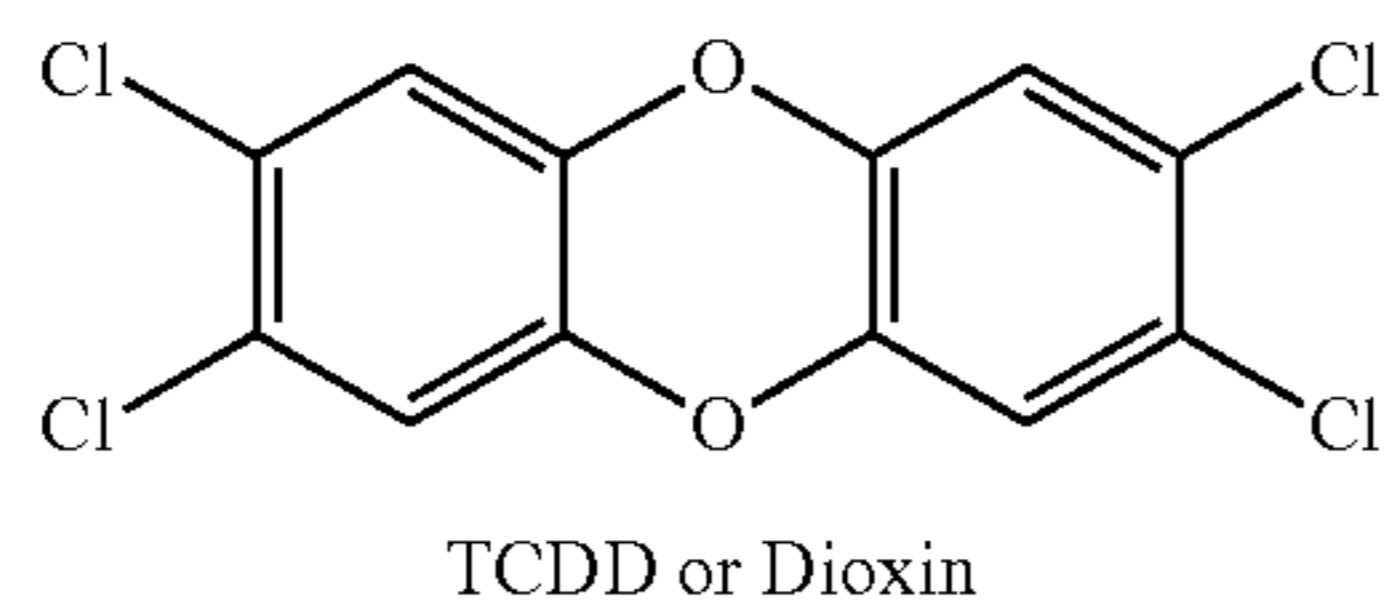
5 The arylhydrocarbon receptor (AhR) is a basic helix-loop-helix transcription factor that is well conserved across many species. Hahn, M. E. *Chem. Biol. Interact.* 2002, 141, 131. AhR readily binds to various endogenous and xenobiotic polycyclic aromatic hydrocarbons. Denison, M. S.; Soshilov, A. A.; He, G.; DeGroot, D. E.; Zhao, B. *Toxicol. Sci.* 2011, 124, 1. It is perhaps best known for its role in conferring the toxicity of environmental pollutant 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD or dioxin) 1 (see below). Bock, K. W. *Biol. Chem.* 2013, 394, 729. AhR binds to TCDD with remarkably high affinity and upon binding, the ligand-receptor complex travels to the nucleus where AhR then dimerizes with the aryl hydrocarbon receptor translocator (ARNT). Knutson, J. C.; Poland, A. *Cell* 1982, 30, 225; Poland, A.; Knutson, J. C. *Annu. Rev. Pharmacol. Toxicol.* 1982, 22, 517. It is this active dimer that functions to promote or repress the transcription of a multitude of different genes, most notably CYP1A1. Schmidt, J. V.; Bradfield, C. A. *Annu. rev. Cell Dev. Biol.* 1996, 12, 55.

AhR activation is highly regulated by a negative feedback mechanism to prevent continuous signaling. Chang, C. Y.; Puga, A. *Mol. Cell Biol.* 1998, 18, 525. It is believed that prolonged AhR signaling is very unfavorable. Mitchell, K. A.; Elferink, C. J. *Biochem. Pharmacol.* 2009, 77, 947. Therefore, it has been proposed that the toxicity of dioxin is due to its exceptionally long metabolic stability (half-life of 7-10 years in human), resulting in a continuously activated AhR. Bock, K. W. *Biol. Chem.* 2013, 394, 729.

It has been postulated that AhR is a target for the treatment of benign prostatic hyperplasia, (Mehta, V.; Vezina, C. M. *Differentiation* 2011, 82, 211) reduction of undesired immune responses during organ transplantation, (Van Voorhis, M.; Fechner, J. H.; Zhang, X.; Mezrich, J. D. *Transplantation* 2013, 95, 983) inflammation disorders, (Beamer, C. A.; Shepherd, D. M. *Semin. Immunopathol.* 2013, 35, 693; Busbee, P. B.; Rouse, M.; Nagarkatti, M.; Nagarkatti, P. S. *Nutrition Rev.* 2013, 71, 353) and certain types of cancer. Safe, S.; Lee, S.-O.; Jin, U.-H. *Toxicol. Sci.* 2013, 135, 1. Peterson and Safe reported that synthetic AhR agonist 6-methyl-1,3,8-trichlorodibenzofuran (MCDF) 2 blocked vascular endothelial growth factor in prostate and conferred protection against prostate cancer in vivo. Fritz, W. A.; Lin, T.-M.; Safe, S.; Moore, R. W.; Peterson, R. E. *Biochem. Pharmacol.* 2009, 77, 1151. Safe also showed that a variety of substituted 3,3'-diindolylmethanes (DIMs) 3, which are also AhR agonists, inhibit tumor growth in rat models. McDougal, A.; Gupta, M. S.; Morrow, D.; Ramamoorthy, K.; Lee, J. E.; Safe, S. H. *Breast Cancer Res. Treat.* 2001, 66, 147. Natural products indolo[3,2-b]carbazole (ICZ) 4, 6-formylindolo[3,2-b]carbazole (FICZ) 5, and malassezin 6 have been demonstrated to be agonists of AhR. Both ICZ and FICZ are categorized as indolocarbazoles, (Knölker, H.-J.; Reddy, K. R. *Chem. Rev.* 2002, 102, 4303; Schmidt, A. W.; Reddy, K. R.; Knolker, H.-J. *Chem. Rev.* 2012, 112, 3193; Wincent, E.; Amini, N.; Luecke, S.; Glatt, H.; Bergman, J.; Crescenzi, C.; Rannug, A.; Rannug, U. J. *Biol. Chem.* 2009, 284, 2690) while malassezin (Wille, G.; Mayser, P.; Thoma, W.; Monsees, T.; Baumgart, A.; Schmitz, H. J.; Schrenk, D.; Polborn, K.; Steglich, W. *Bioorg. Med. Chem.* 2001, 9, 955; Kramer, H. J.; Podobinska, M.; Bartsch, A.; Battmann, A.; Thoma, W.; Bernd, A.; Kummer, W.; Irlinger, B.; Steglich, W.; Mayser, P. *ChemBiochem* 2005, 6, 860) is a formylated 2,3'-diindolylmethane.

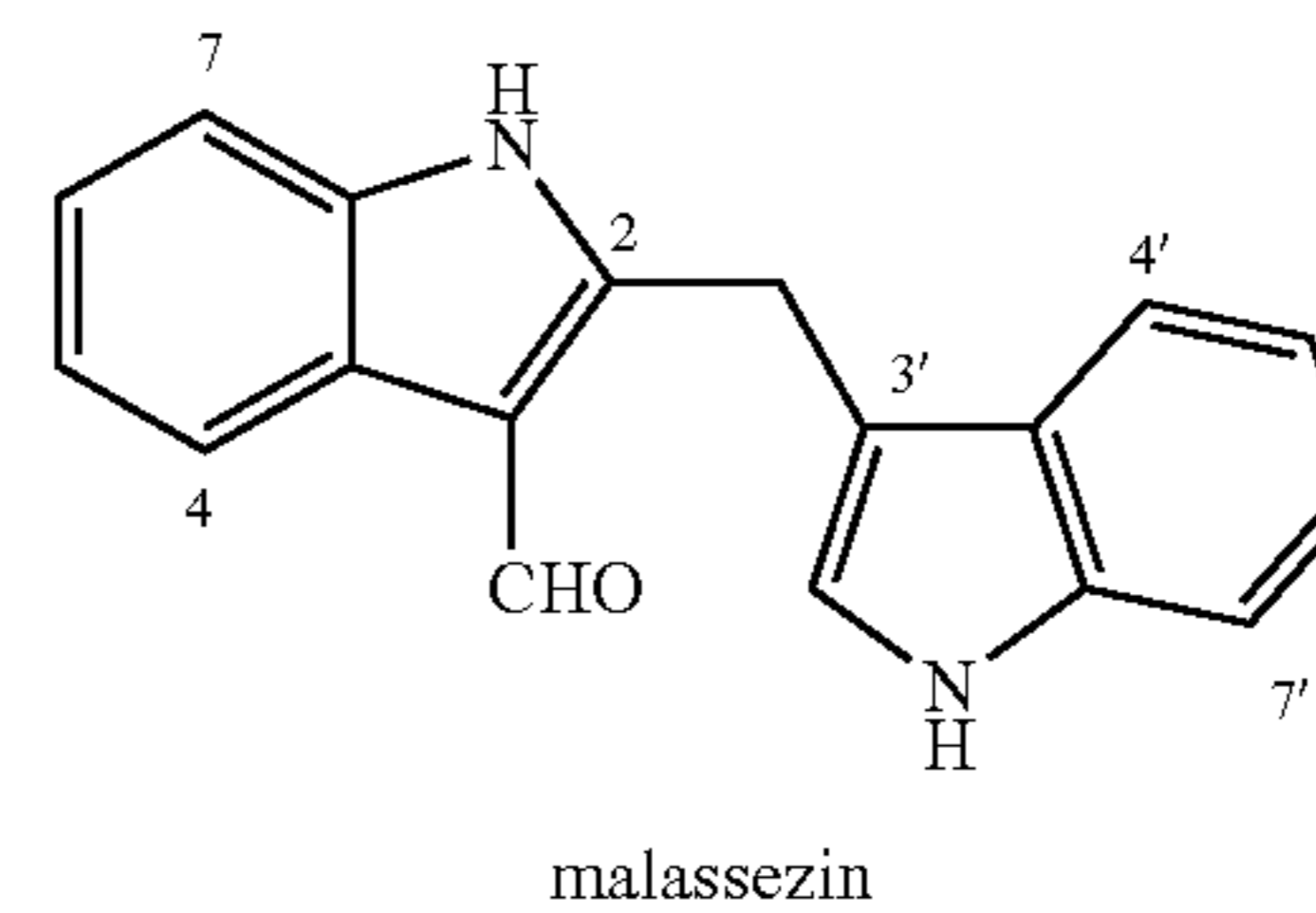
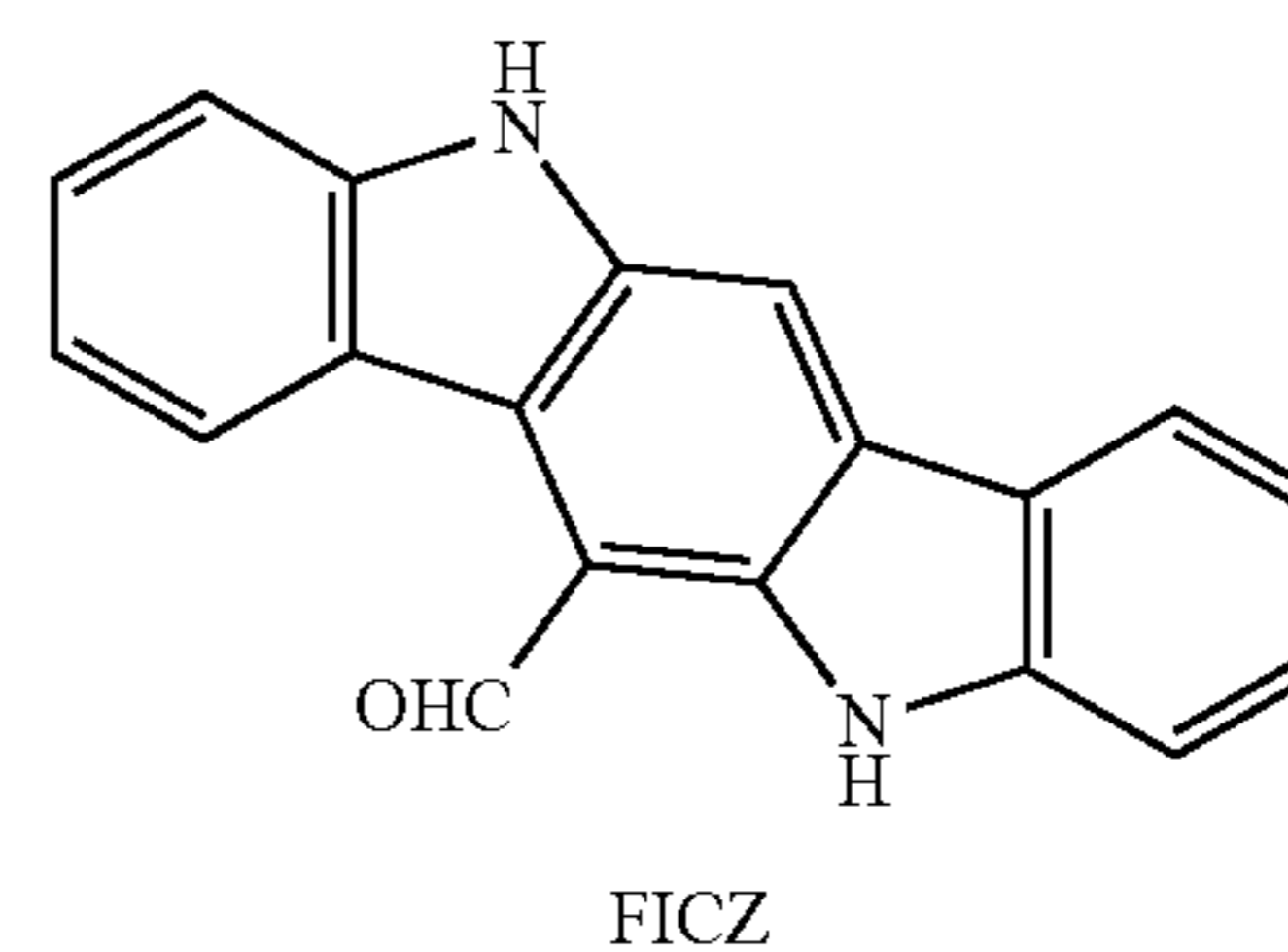
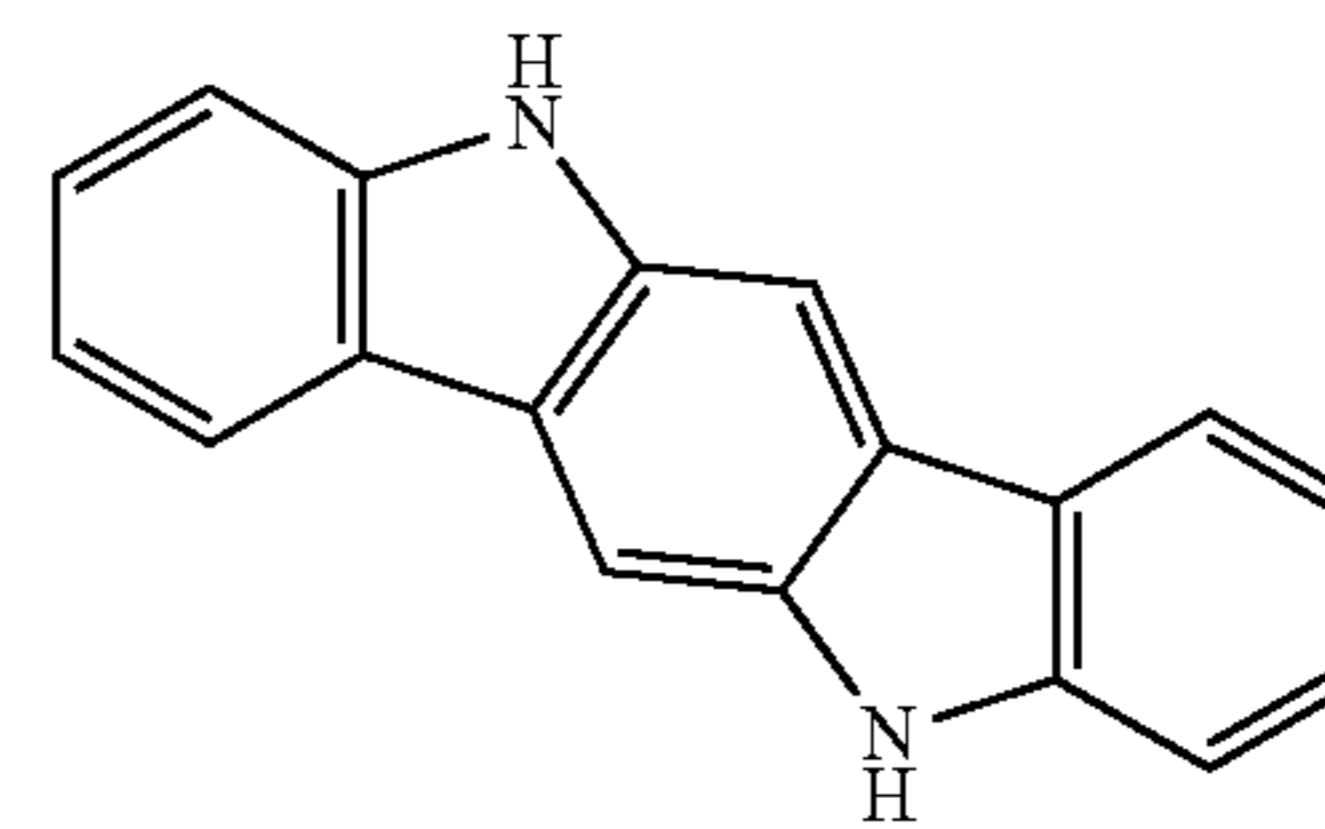
63

Nguyen, L. P.; Bradfield, C. A. *Chem. Res. Toxicol.* 2008, 21, 102. Recent studies suggested that FICZ had anti-asthmatic effects by inhibiting Th2 cytokine production in a mouse model. Jeong, K.-T.; Hwang, S.-J.; Oh, G.-S.; Park, J.-H. *Int. Immunopharmacol.* 2012, 13, 377. Herein we the development of selective AhR modulators by preparing an assortment of 2,3'-diindolylmethanes.



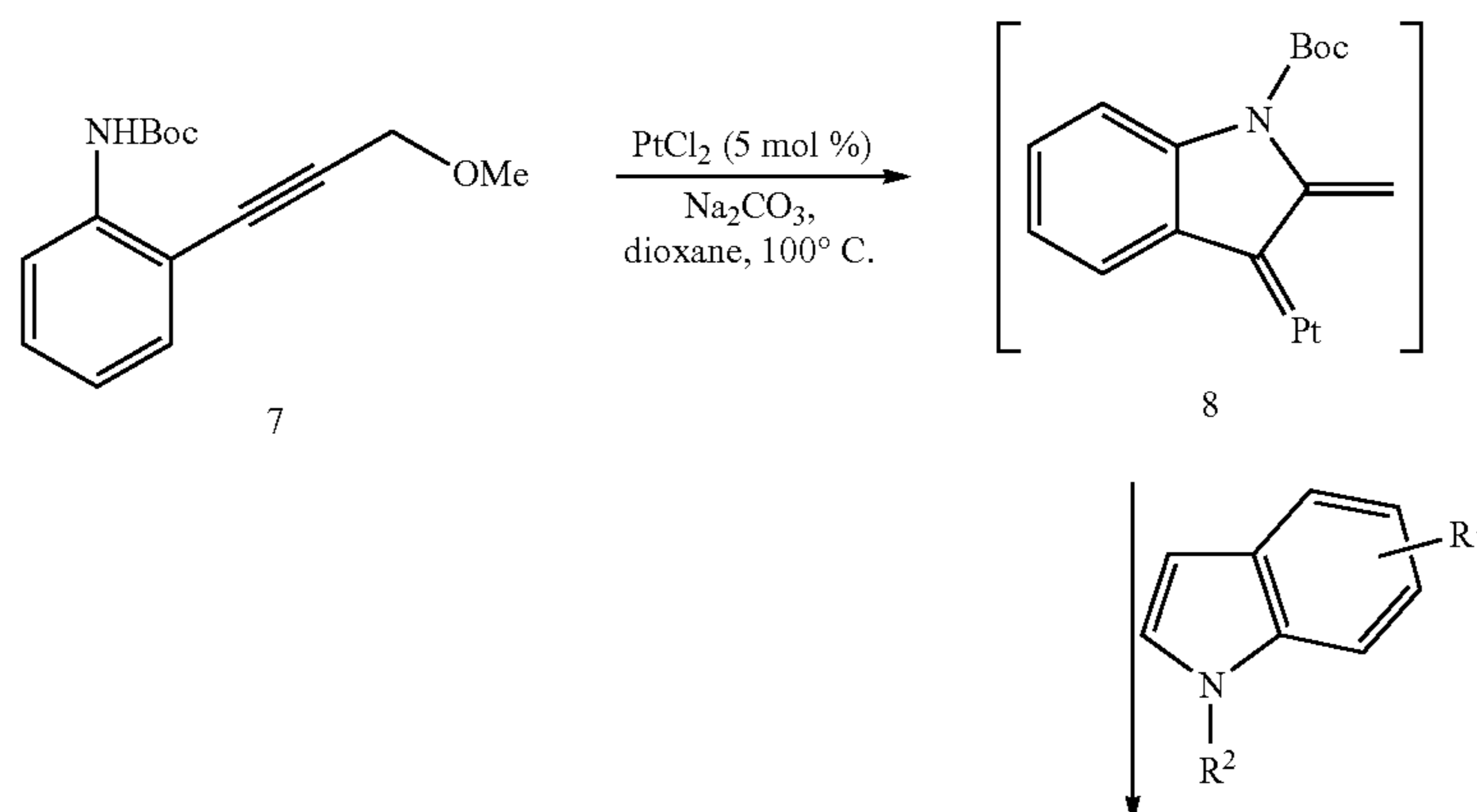
64

-continued

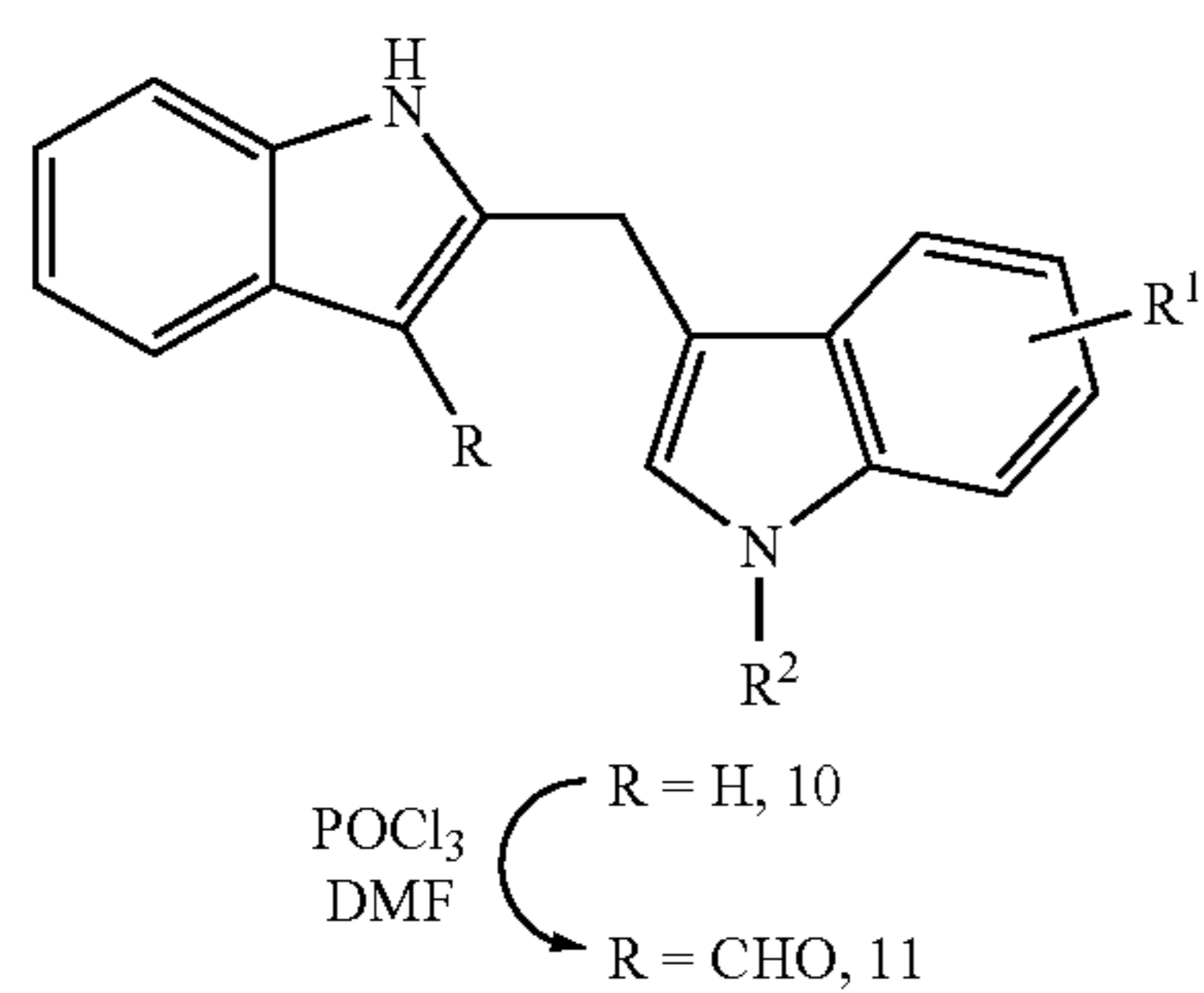


The platinum-catalyzed indole annulation/arylation cascade reaction for the synthesis of diindolylmethane 9 from propargylic ether 7 is shown in Reaction Scheme 4. As described above, this route has demonstrated utility in the total synthesis of the natural product malassezin. Based on this method, a collection of malassezin analogues 10 and 11 were prepared following the sequence in Reaction Scheme 4. After the formation of 9 using the indole annulation/arylation protocol, the Boc protecting group was cleaved under thermal conditions to produce diindolylmethanes 10, which were then treated with POCl<sub>3</sub> and DMF to give the formylated malassezin analogues 11. Shu, D.; Winston-McPherson, G. N.; Song, W.; Tang, W. *Org. Lett.* 2013, 15, 4162.

Reaction Scheme 4. Synthesis of 2,3'-Diindolylmethanes

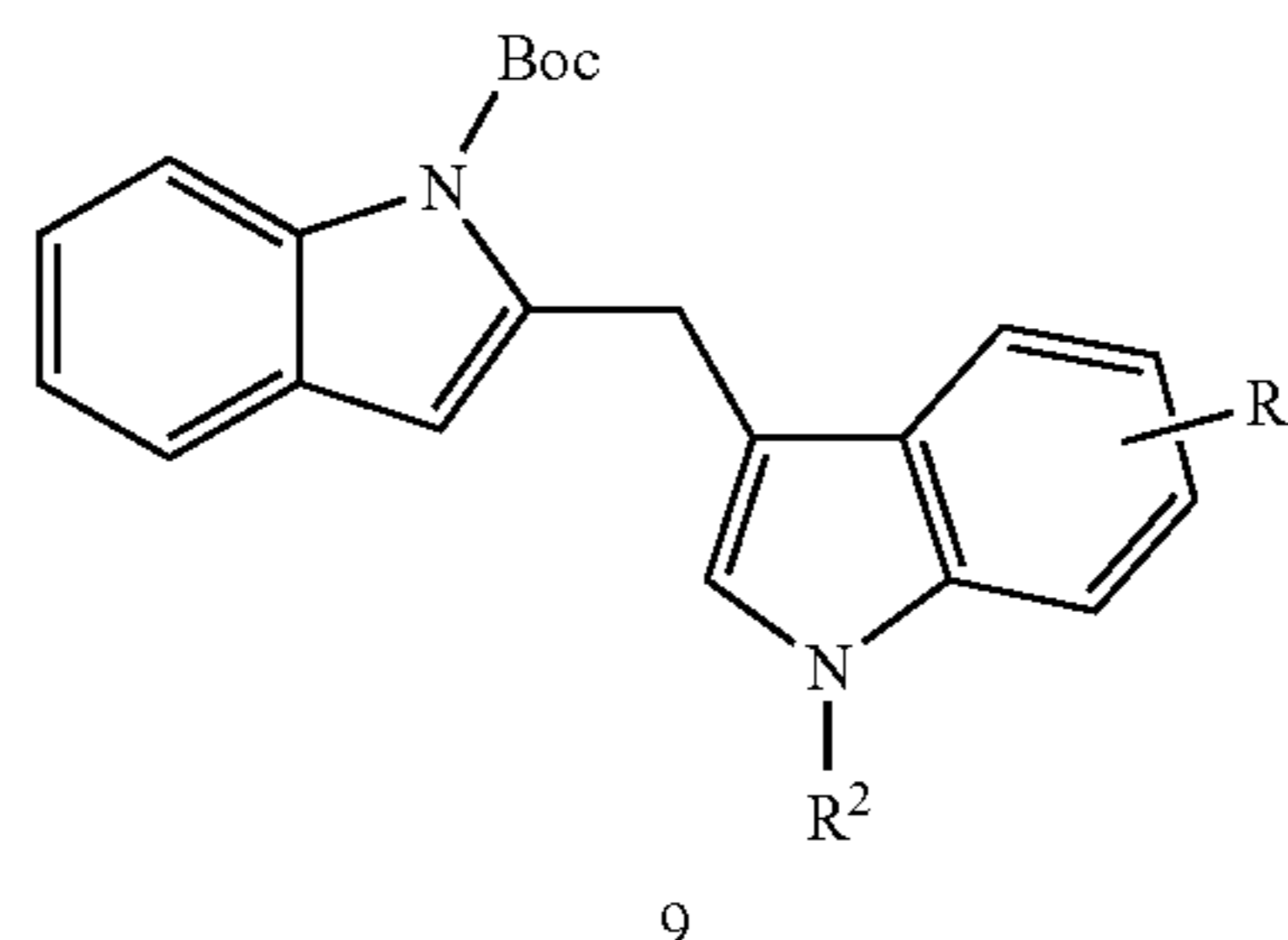


65



-continued

160° C.



66

The bioactivity of malassezin analogs was then investigated. The well-documented ethoxyresorufin-O-deethylase (EROD) assay was used to determine the  $\text{EC}_{50}$  values of the compounds towards AhR activation in HepG2 cells. Donato, M. T.; Gomezlechon, M. J.; Castell, J. V. *Anal. Biochem.* 1993, 213, 29; van Tonder, J. J., University of Pretoria Z. A., Thesis, 2011. This assay measures the induction of cytochrome P450-1A1 (CYP1A1), which is a major outcome of AhR activation. Whyte, J. J.; Jung, R. E.; Schmitt, C. J.; Tillitt, D. E. *Crit. Rev. Toxicol.* 2000, 30, 347. CYP1A1 selectively converts 7-ethoxyresorufin to the fluorescent product resorufin.

Malassezin served as the positive control (Table 4). The  $\text{EC}_{50}$  values of the malassezin analogs varied quite dramatically depending on their respective substitution pattern. For the halogenated 2,3'-diindolylmethanes 11a-c, 5'-chlorination resulted in a compound (11a) more potent than the positive control, while 7'-chlorination gave a slightly weaker agonist (11b). Compound 11c, with a methoxy substitution on the 5'-position, behaved similarly to malassezin. Interestingly, compound 11d with an N-methyl group on the 1'-position was surprisingly potent; its  $\text{EC}_{50}$  value was about five times lower than that of malassezin.

The importance of the formyl group in malassezin analogues for AhR activation was also investigated. In the case of compound pair 10a/11a, the formyl group contributed significantly to the potency of 11a. In contrast, other non-formylated compounds including 6', 10c, and 10d have similar potency as their formylated counterparts (6, 11c, and 11d).

Up to 12-fold increase of signal over DMSO treatment was observed for many of the malassezin analogs. Even at 10 nM concentration, compounds 11a and 11d could induce 5- and 6-fold increase of signals, respectively (data not shown).

TABLE 4

AhR Activity of Diindolylmethanes	
Compounds	$\text{EC}_{50}$ ( $\mu\text{M}$ )
6	0.27 $\pm$ 0.1

TABLE 4-continued

AhR Activity of Diindolylmethanes	
Compounds	$\text{EC}_{50}$ ( $\mu\text{M}$ )
11a	0.093 $\pm$ 0.15
11b	0.32 $\pm$ 0.1
11c	0.23 $\pm$ 0.1
11d	0.055 $\pm$ 0.03
6'	0.215 $\pm$ 0.46

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TABLE 4-continued

AhR Activity of Diindolylmethanes	
Compounds	EC <sub>50</sub> (μM)
10a	>6.7
10c	0.094 ± 0.27
10d	0.086 ± 0.04

Selected compounds were also tested for their ability to induce glucagon-like peptide 1 (GLP-1) in standard in vivo testing. Glucagon-like peptide 1 (GLP-1) is derived from transcription of the proglucagon gene followed by post-translational modifications of proglucagon to the following biologically active peptides: GLP-1 (7-37) and GLP-1 (7-36)NH<sub>2</sub>. GLP-1 secretion by ileal L cells is dependent on the presence of nutrients in the lumen of the small intestine. GLP-1 is a potent anti-hyperglycemic hormone inducing glucose-dependent insulin secretion and suppressing glucagon secretion. The glucose dependency of this mechanism is particularly important because GLP-1 does not stimulate insulin secretion and cause hypoglycemia when plasma glucose concentrations are in the normal fasting range.

The GLP-1 secretion, diabetes phenotypic testing identifies compounds that stimulate secretion of glucagon-like peptide one (GLP-1) in mouse and human cell lines derived from gastrointestinal tract tissue. GLP-1 secretion is measured using an Eli Lilly & Company (Indianapolis, Ind., USA) proprietary ELISA assay that was specifically designed to detect the appropriate forms of GLP-1 secreted from these cells. (Eli Lilly operates a program known Open Innovation Drug Discovery that performs such testing. See <https://openinnovation.lilly.com/dd/>.) If active in the cell-based GLP-1 assay, molecules are further tested for selectivity in assays that measure activation of GPCRs known to stimulate GLP-1 secretion. See *Glucagon-Like Peptide 1-Based Therapies for Type 2 Diabetes: A Focus on Exenatide*; Kathleen Dungan and John B. Buse; *Clinical Diabetes*: 29 (1), (Winter 2011); and *Glucagon-Like Peptide 1 Secretion by the L-Cell*; Gareth E. Kim and Patricia L. Brubaker; *Diabetes*: 55 (supplement 2), (December, 2006).

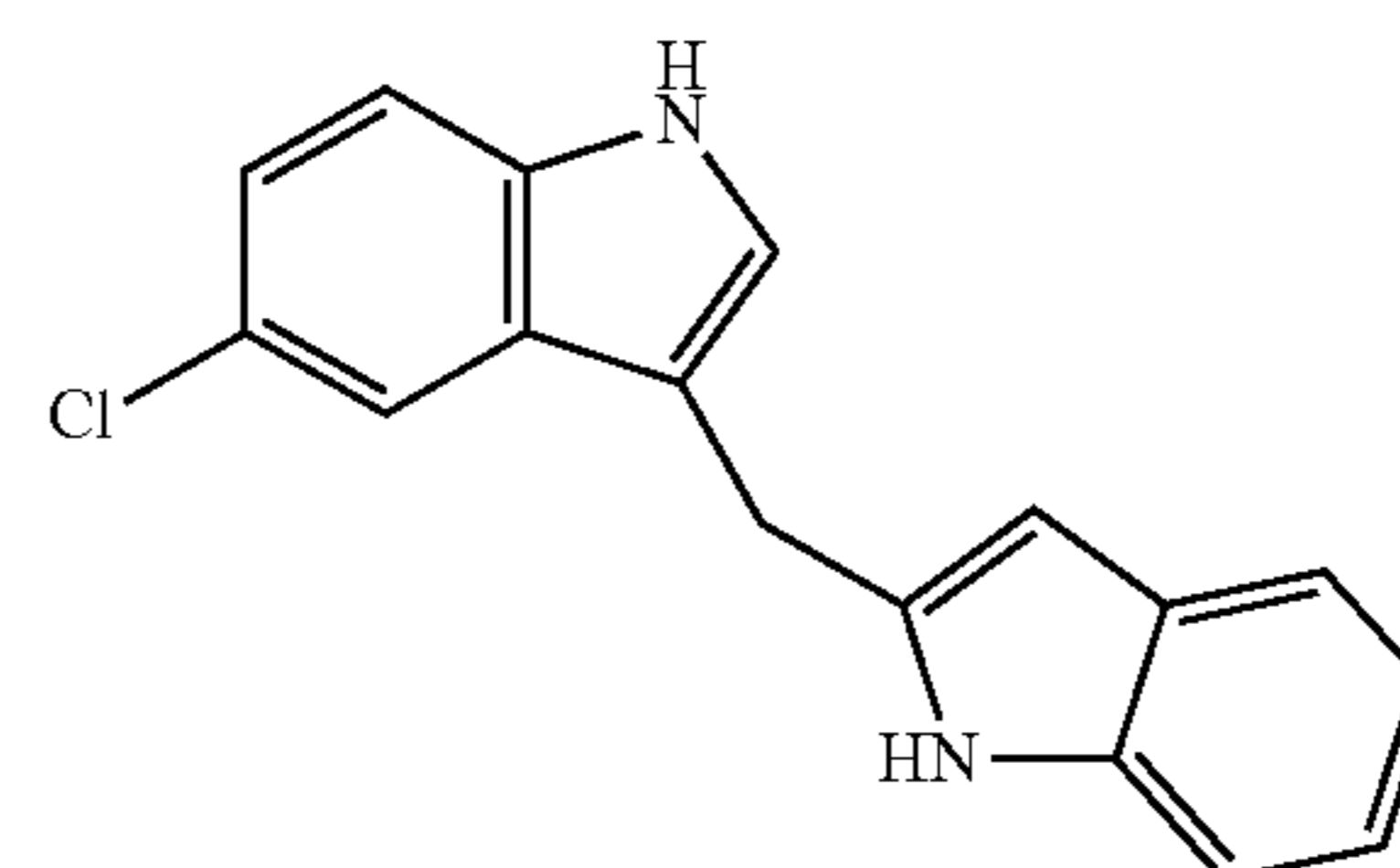
The compounds were also tested for their inhibitory activity against proprotein convertase subtilisin/kexin type 9 (PCSK9). PCSK9 plays a major regulatory role in cholesterol homeostasis, and thus is an important drug target for

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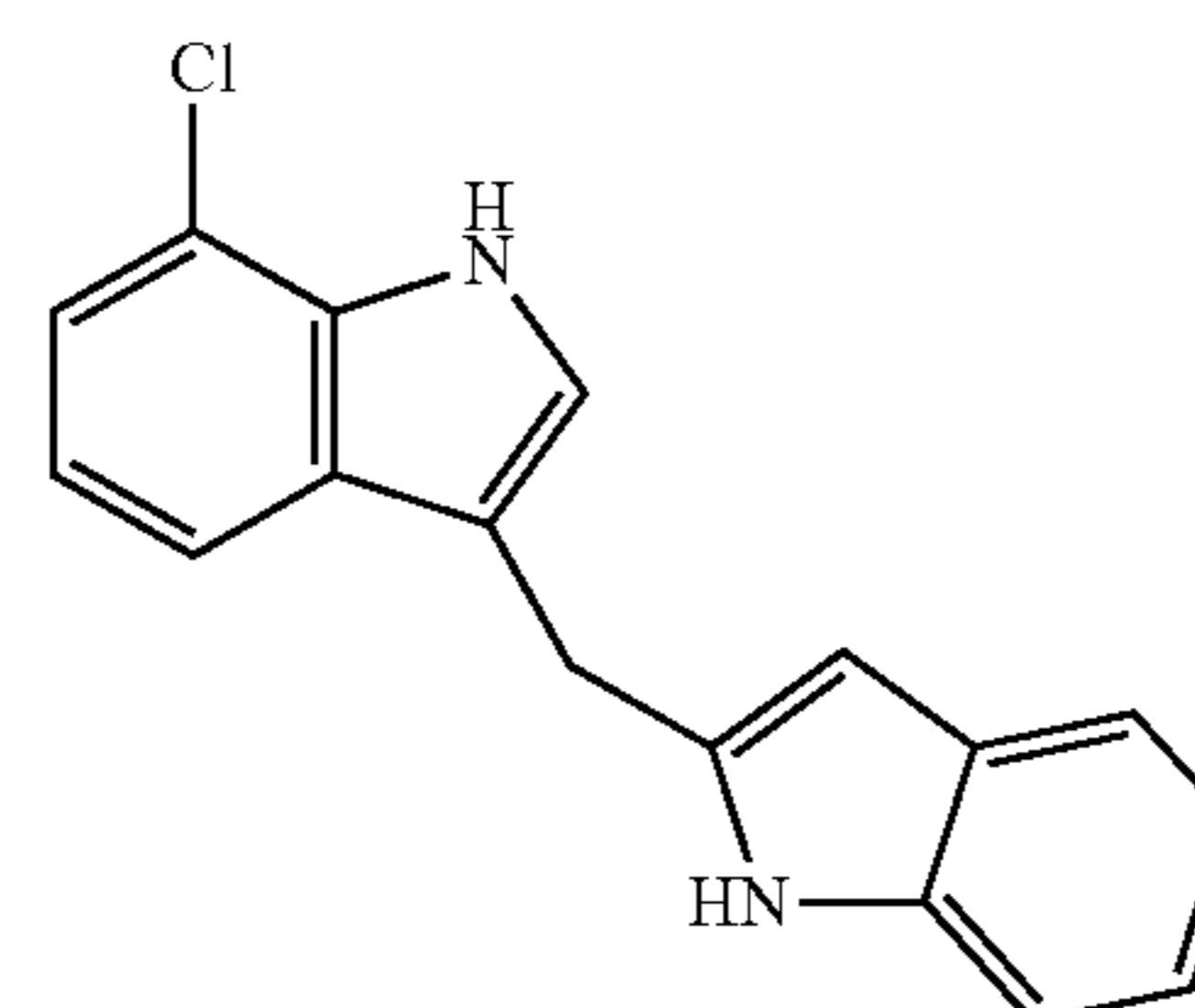
treating hypercholesterolemia. See, for example, Steinberg D, Witztum J L (June 2009). "Inhibition of PCSK9: a powerful weapon for achieving ideal LDL cholesterol levels". *Proc. Natl. Acad. Sci. U.S.A.* 106 (24): 9546-7. The results are shown in Table 5.

TABLE 5

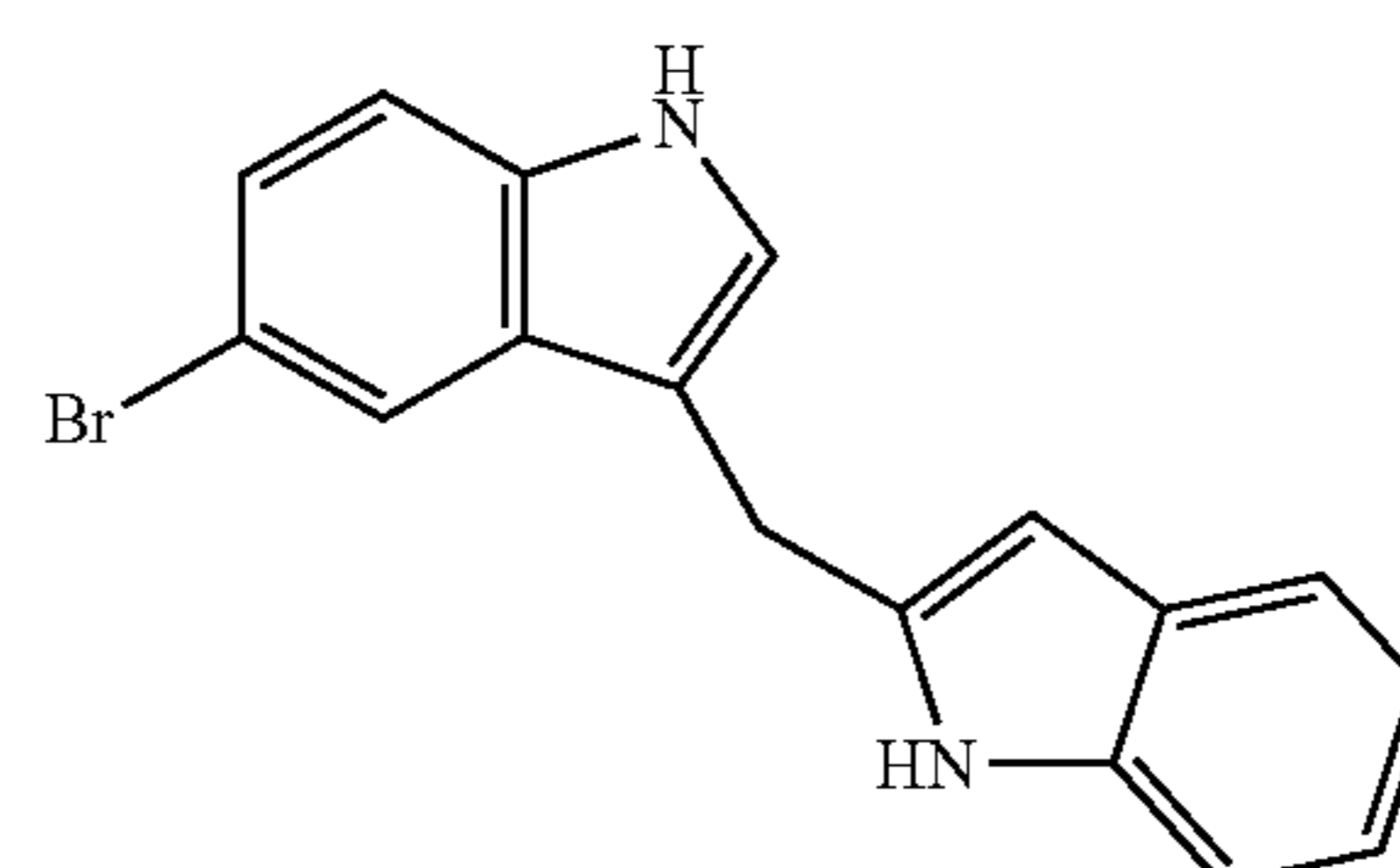
PCSK9 and GLP-1 Activity.



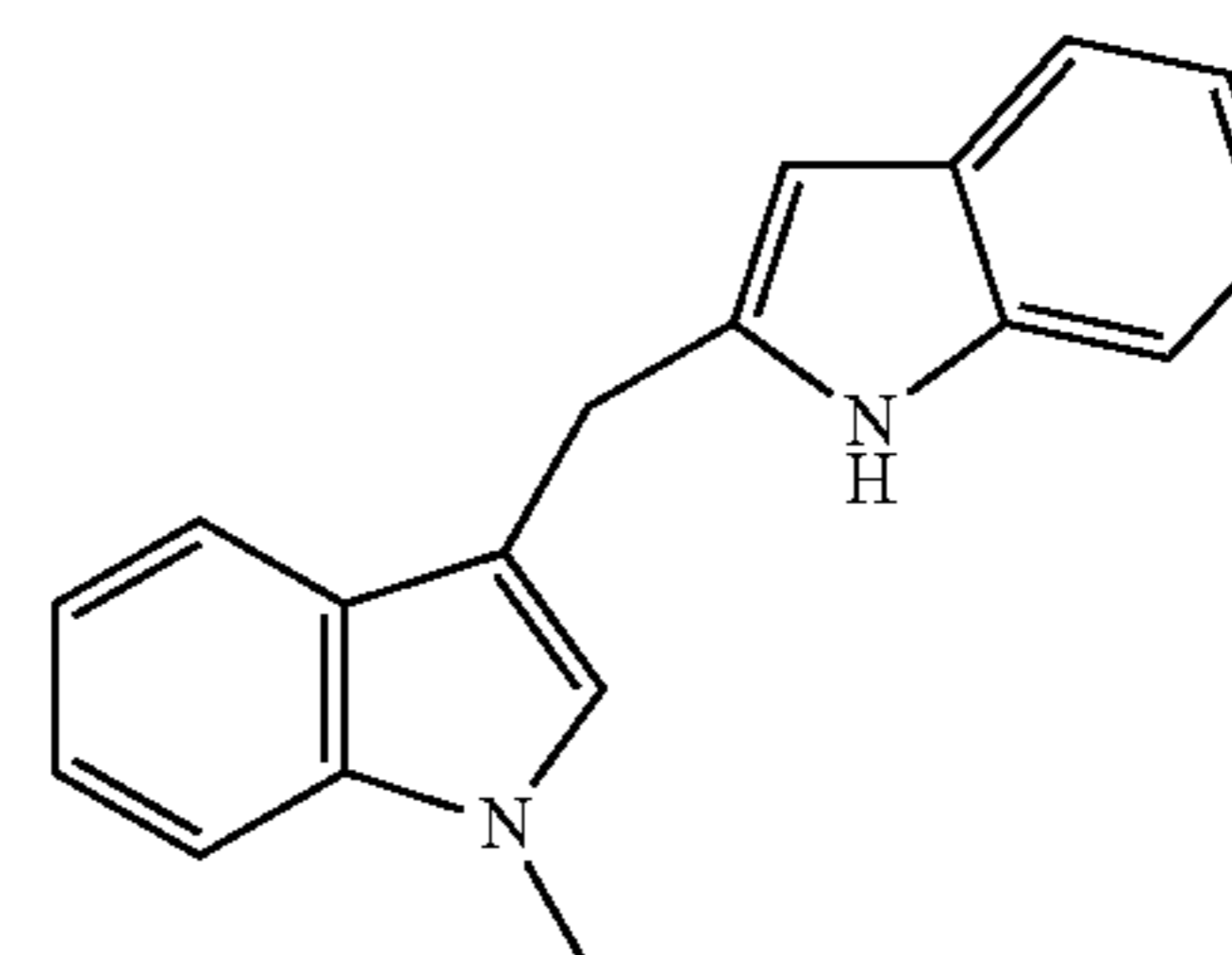
2351377819  
PCSK9, IC<sub>50</sub> = 10 μM  
GLP-1, EC<sub>50</sub> = 14.8 μM



2351377820  
PCSK9, IC<sub>50</sub> = 2.8 μM  
GLP-1, EC<sub>50</sub> = 7.2 μM



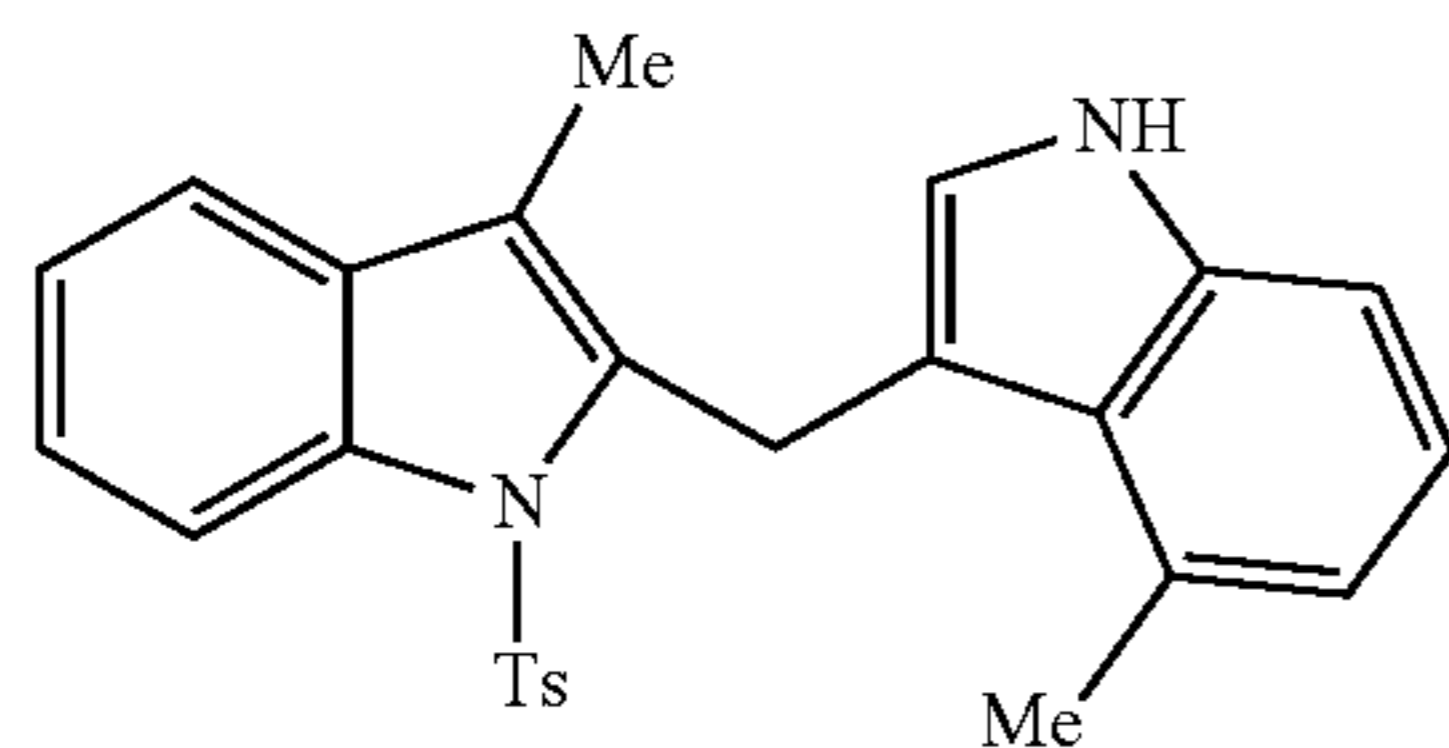
2351377823  
GLP-1, EC<sub>50</sub> = 6.8 μM



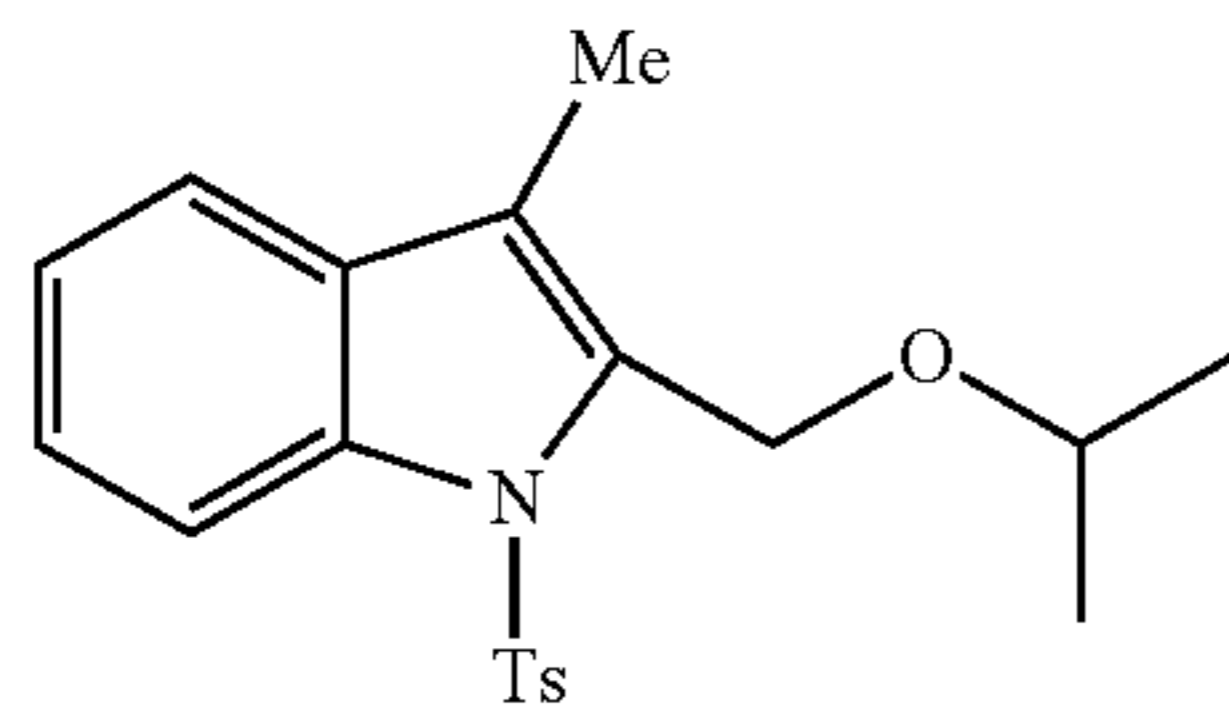
2351377824  
PCSK9, IC<sub>50</sub> = 17.9 μM  
(AhR, EC<sub>50</sub> = 0.09 μM)

TABLE 5-continued

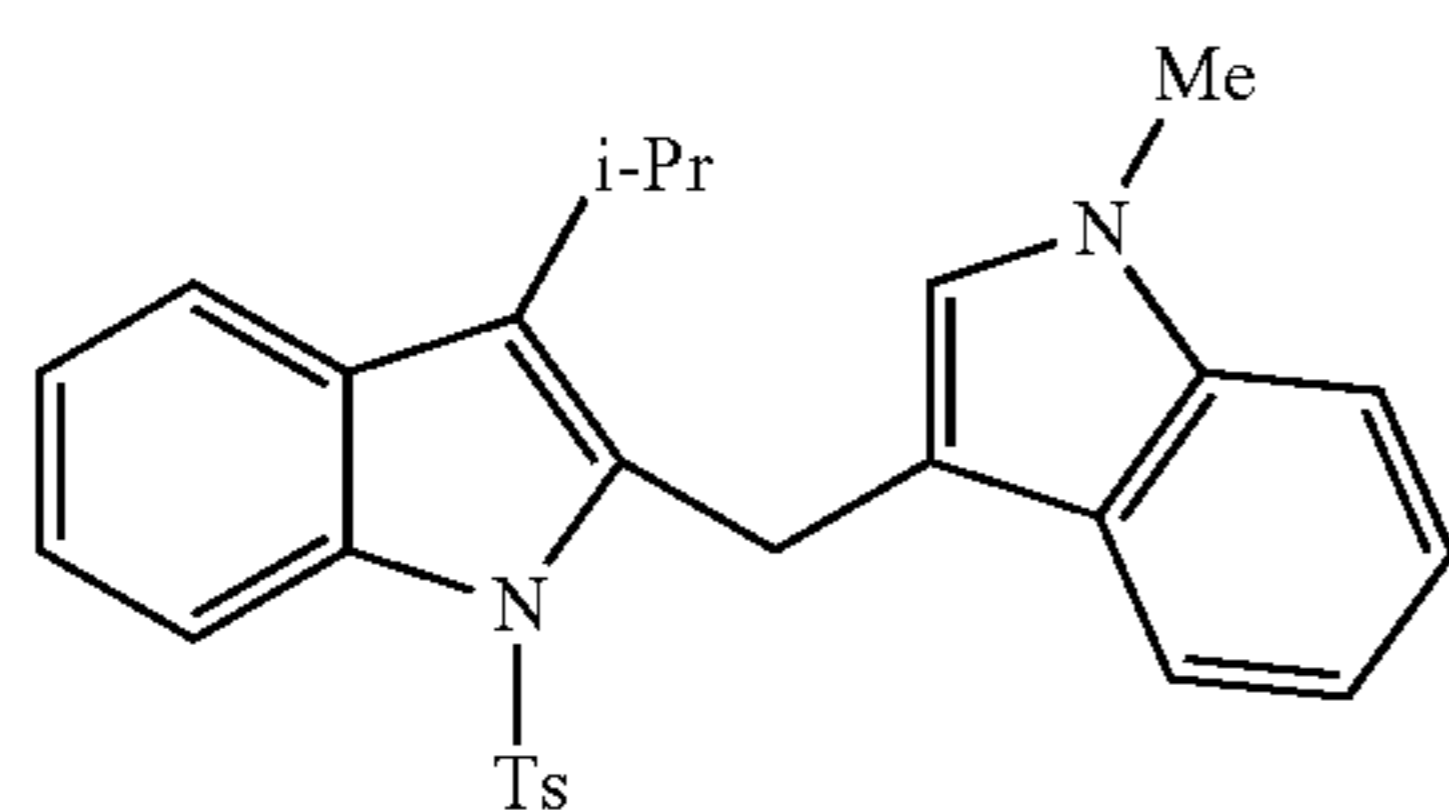
PCSK9 and GLP-1 Activity.



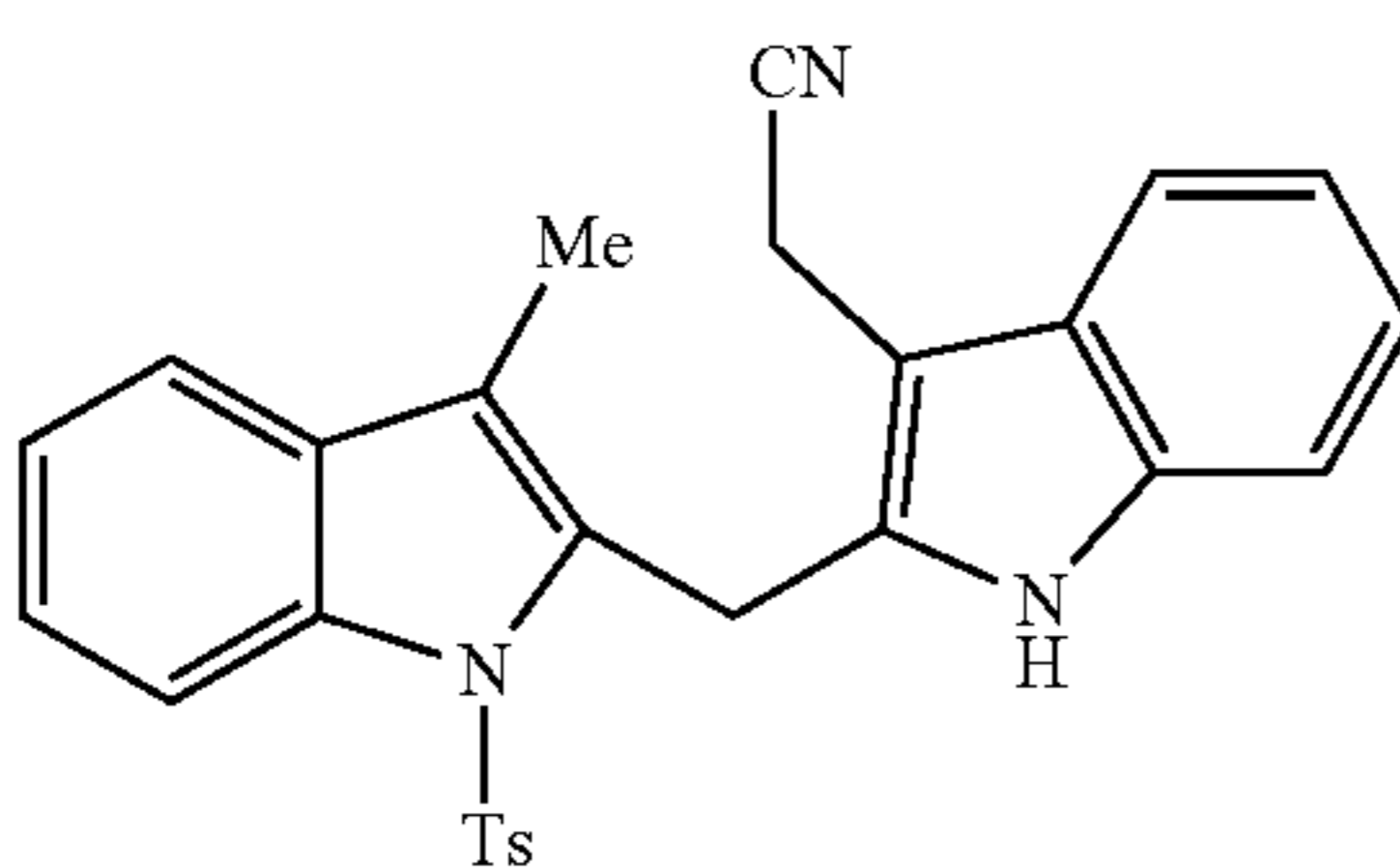
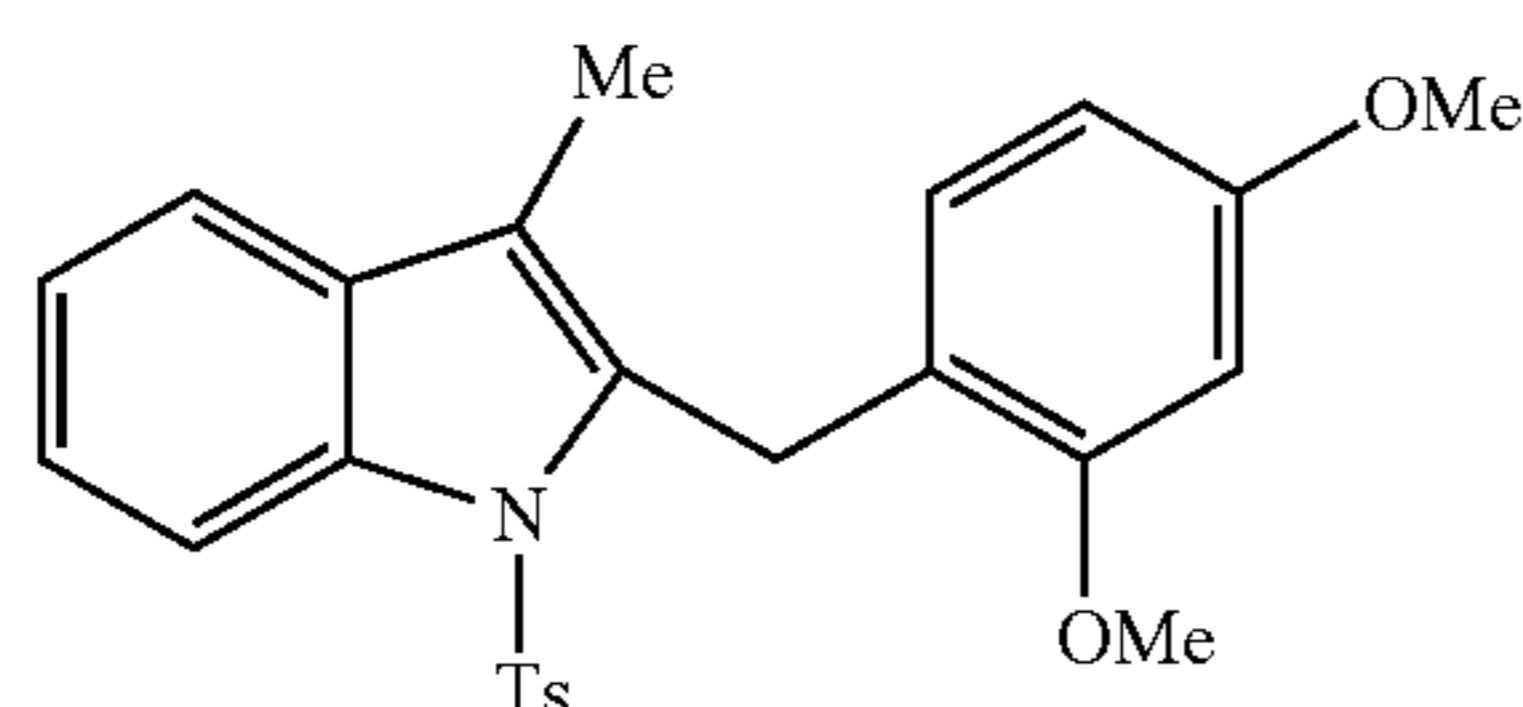
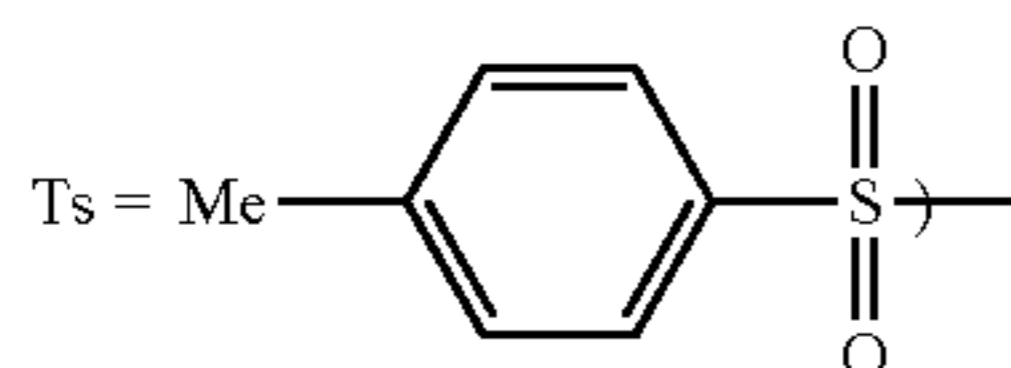
GLP-1, EC50 = 2.6 uM



GLP-1, EC50 = 7.3 uM



PCSK9, IC50 = 1.1 uM

IL17, IC50 = 3.1 uM  
IL5, IC50 > 30 uMPCSK9, IC50 = 1.1 uM  
GLP-1, EC50 = 2.9 uM

These examples demonstrate the utility of the disclosed compounds to treat ailments in mammals that are mediated by the arylhydrocarbon receptor, GLP-1, and/or PCSK9.

## 12. X-Ray Crystallography Studies:

### (12.1) Structural Report on Compound 9b

#### (12.1.1) Data Collection:

A colorless crystal with approximate dimensions  $0.56 \times 0.48 \times 0.41 \text{ mm}^3$  was selected under oil under ambient conditions and attached to the tip of a MiTeGen MicroMount (MiTeGen, LLC, Ithaca, N.Y., USA). The crystal was

mounted in a stream of cold nitrogen at 100(1) K and centered in the X-ray beam by using a video camera.

The crystal evaluation and data collection were performed on a Bruker Quazar SMART APEXII diffractometer (Bruker AXS, Inc., Madison, Wis., USA) with Mo  $K_{\alpha}$  ( $\lambda=0.71073 \text{ \AA}$ ) radiation and the diffractometer-to-crystal distance of 4.96 cm.

The initial cell constants were obtained from three series of  $\omega$  scans at different starting angles. Each series consisted of 12 frames collected at intervals of  $0.5^\circ$  in a  $6^\circ$  range about  $\omega$  with the exposure time of 2 seconds per frame. The reflections were successfully indexed by an automated indexing routine built in the APEXII program suite. The final cell constants were calculated from a set of 9673 strong reflections from the actual data collection.

The data were collected by using the full sphere data collection routine to survey the reciprocal space to the extent of a full sphere to a resolution of  $0.70 \text{ \AA}$ . A total of 48251 data were harvested by collecting 6 sets of frames with  $0.5^\circ$  scans in  $\omega$  and  $\varphi$  with exposure times of 20 sec per frame. These highly redundant datasets were corrected for Lorentz and polarization effects. The absorption correction was based on fitting a function to the empirical transmission surface as sampled by multiple equivalent measurements. Bruker-AXS. (2007-2014) APEX2 (Ver. 2014.1-1), SADABS (2012-1), and SAINT+ (Ver. 8.32A) Software Reference Manuals. Bruker-AXS, Madison, Wis., USA.

#### (12.1.2) Structure Solution and Refinement:

The systematic absences in the diffraction data were uniquely consistent for the space group  $P2_1/n$  that yielded chemically reasonable and computationally stable results of refinement. Sheldrick, G. M. (2008) SHELXL. *Acta Cryst.* A64, 112-122. Dolomanov, O. V.; Bourhis, L. J.; Gildea, R. J.; Howard, J. A. K.; Puschmann, H. "OLEX2: a complete structure solution, refinement and analysis program". *J. Appl. Cryst.* (2009) 42, 339-341. Guzei, I. A. (2013). Internal laboratory computer programs Gn.

A successful solution by the direct methods provided most non-hydrogen atoms from the E-map. The remaining non-hydrogen atoms were located in an alternating series of least-squares cycles and difference Fourier maps. All non-hydrogen atoms were refined with anisotropic displacement coefficients. All hydrogen atoms except H2(N2) were included in the structure factor calculation at idealized positions and were allowed to ride on the neighboring atoms with relative isotropic displacement coefficients. The H2 atom was located in the difference Fourier map and refined independently.

The final least-squares refinement of 277 parameters against 4971 data resulted in residuals R (based on  $F^2$  for  $I \geq 2\sigma$ ) and wR (based on  $F^2$  for all data) of 0.0370 and 0.1014, respectively. The final difference Fourier map was featureless.

#### (12.1.3) Summary for 9b:

Crystal Data for  $C_{25}H_{22}N_2O_2S$  (M=414.50): monoclinic, space group  $P2_1/n$  (no. 14),  $a=13.247(3) \text{ \AA}$ ,  $b=11.312(3) \text{ \AA}$ ,  $c=14.218(4) \text{ \AA}$ ,  $\beta=109.780(16)^\circ$ ,  $V=2005.0(9) \text{ \AA}^3$ ,  $Z=4$ ,  $T=100.01 \text{ K}$ ,  $\mu(\text{MoK}\alpha)=0.187 \text{ mm}^{-1}$ ,  $D_{\text{calc}}=1.373 \text{ g/mm}^3$ , 48251 reflections measured ( $3.634 \leq 2\theta \leq 56.666$ ), 4971 unique ( $R_{\text{int}}=0.0212$ ,  $R_{\text{sigma}}=0.0096$ ) which were used in all calculations. The final  $R_1$  was 0.0370 ( $I > 2\sigma(I)$ ) and  $wR_2$  was 0.1014 (all data).

TABLE 6

Crystal data and structure refinement for 9b.	
Identification code	9b
Empirical formula	C <sub>25</sub> H <sub>22</sub> N <sub>2</sub> O <sub>2</sub> S
Formula weight	414.50
Temperature/K	100.01
Crystal system	monoclinic
Space group	P2 <sub>1</sub> /n
a/Å	13.247(3)
b/Å	11.312(3)
c/Å	14.218(4)
α/°	90
β/°	109.780(16)
γ/°	90
Volume/Å <sup>3</sup>	2005.0(9)
Z	4
ρ <sub>calc</sub> /mg/mm <sup>3</sup>	1.373
m/mm <sup>-1</sup>	0.187
F(000)	872.0
Crystal size/mm <sup>3</sup>	0.56 × 0.48 × 0.41
Radiation	MoKα (λ = 0.71073)
2θ range for data collection	3.634 to 56.666°
Index ranges	-17 ≤ h ≤ 17, -15 ≤ k ≤ 15, -18 ≤ l ≤ 18
Reflections collected	48251
Independent reflections	4971 [R <sub>int</sub> = 0.0212, R <sub>sigma</sub> = 0.0096]
Data/restraints/parameters	4971/0/277
Goodness-of-fit on F <sup>2</sup>	1.046
Final R indexes [I ≥ 2σ(I)]	R <sub>1</sub> = 0.0370, wR <sub>2</sub> = 0.1000
Final R indexes [all data]	R <sub>1</sub> = 0.0384, wR <sub>2</sub> = 0.1014
Largest diff. peak/hole/e Å <sup>-3</sup>	0.42/-0.37

TABLE 7

Fractional Atomic Coordinates (×10 <sup>4</sup> ) and Equivalent Isotropic Displacement Parameters (Å <sup>2</sup> × 10 <sup>3</sup> ) for 9b. U <sub>eq</sub> is defined as 1/3 of the trace of the orthogonalised U <sub>ij</sub> tensor.					
Atom	x	y	z	U(eq)	
S1	5203.5(2)	2906.9(2)	7821.4(2)	16.03(9)	
O1	4426.5(7)	3399.6(8)	8208.3(6)	20.49(18)	
O2	6123.7(7)	2323.2(8)	8489.8(6)	21.52(19)	
N1	5672.5(8)	4022.4(9)	7323.6(7)	17.15(19)	
N2	4941.6(9)	6834.2(10)	9582.1(8)	21.0(2)	
C1	4542.4(9)	1943.3(10)	6846.3(8)	15.6(2)	
C2	5069.0(9)	930.1(11)	6711.4(9)	18.5(2)	
C3	4529(1)	153.3(11)	5951.7(9)	20.7(2)	
C4	3481(1)	380.1(11)	5329.1(9)	20.3(2)	
C5	2970.8(10)	1407.1(11)	5486.5(9)	20.8(2)	
C6	3488.6(9)	2187.9(10)	6246.2(9)	18.7(2)	
C7	2898.2(11)	-481.8(13)	4521.2(11)	29.8(3)	
C8	6562.0(9)	3887.2(10)	6989.1(9)	17.8(2)	
C9	7359.5(10)	3023.6(11)	7206.9(10)	21.9(2)	
C10	8149.9(10)	3154.1(12)	6770.9(11)	25.6(3)	
C11	8145.1(10)	4106.2(13)	6143.7(11)	26.7(3)	
C12	7347.8(10)	4959.2(12)	5930.9(10)	23.5(3)	
C13	6544.0(9)	4846.2(10)	6358.4(9)	18.4(2)	
C14	5618.7(9)	5564.8(10)	6283.4(8)	18.0(2)	
C15	5332.3(11)	6691.0(11)	5700.7(10)	23.5(2)	
C16	5092.3(9)	5054.7(10)	6847.5(8)	16.9(2)	
C17	4114.4(9)	5513.7(11)	7031.2(9)	18.4(2)	
C18	4345.8(9)	6235.3(10)	7974.0(9)	17.8(2)	
C19	3989.4(9)	7426.2(11)	8024.3(9)	18.0(2)	
C20	3392.2(10)	8242.7(11)	7312(1)	21.7(2)	
C21	3204.6(11)	9355.7(12)	7622.9(10)	24.8(3)	
C22	3585.4(10)	9663.8(11)	8640.2(10)	25.0(3)	
C23	4162.8(10)	8875.9(11)	9365(1)	21.8(2)	
C24	4368.4(9)	7764.8(11)	9043.6(9)	18.7(2)	
C25	4920.2(10)	5917.3(11)	8936.3(9)	20.1(2)	

TABLE 8

Anisotropic Displacement Parameters (Å<sup>2</sup> × 10<sup>3</sup>) for 9b. The Anisotropic displacement factor exponent takes the form:  

$$-2\pi^2[h^2a^*U_{11} + 2hka^*b^*U_{12} + \dots]$$

Atom	U <sub>11</sub>	U <sub>22</sub>	U <sub>33</sub>	U <sub>23</sub>	U <sub>13</sub>	U <sub>12</sub>
S1	18.20(15)	15.47(14)	13.91(14)	-0.78(9)	4.77(10)	-0.36(9)
O1	24.3(4)	20.4(4)	19.2(4)	-1.8(3)	10.5(3)	-0.3(3)
O2	22.6(4)	21.6(4)	16.4(4)	0.7(3)	1.3(3)	0.9(3)
N1	17.3(4)	15.0(4)	20.1(5)	-0.2(4)	7.6(4)	0.5(3)
N2	24.8(5)	19.3(5)	18.9(5)	-2.3(4)	7.4(4)	0.0(4)
C1	18.3(5)	14.8(5)	13.5(5)	-0.5(4)	5.1(4)	-1.8(4)
C2	17.5(5)	18.9(5)	18.6(5)	0.1(4)	5.6(4)	1.1(4)
C3	22.6(6)	18.6(5)	21.9(6)	-3.3(4)	8.8(5)	0.9(4)
C4	22.5(6)	21.2(6)	17.4(5)	-2.4(4)	6.8(4)	-3.5(4)
C5	18.9(5)	22.2(6)	18.5(5)	1.0(4)	2.6(4)	-0.1(4)
C6	19.2(5)	16.6(5)	19.3(5)	1.1(4)	5.4(4)	1.4(4)
C7	27.3(6)	31.0(7)	27.3(6)	-11.4(5)	4.5(5)	-4.2(5)
C8	16.0(5)	18.1(5)	19.1(5)	-4.9(4)	5.7(4)	-2.5(4)
C9	18.1(5)	19.4(5)	27.3(6)	-3.0(5)	6.7(5)	-0.2(4)
C10	17.8(5)	24.7(6)	34.5(7)	-7.0(5)	9.0(5)	0.4(5)
C11	21.7(6)	28.8(7)	33.9(7)	-8.2(5)	15.0(5)	-5.0(5)
C12	24.7(6)	22.7(6)	26.2(6)	-4.7(5)	12.5(5)	-5.6(5)
C13	19.2(5)	17.0(5)	19.0(5)	-5.5(4)	6.5(4)	-2.9(4)
C14	20.5(5)	16.1(5)	17.3(5)	-3.3(4)	6.5(4)	-1.1(4)
C15	28.2(6)	19.3(6)	23.4(6)	2.0(5)	9.5(5)	-0.1(5)
C16	18.3(5)	14.8(5)	16.6(5)	-2.4(4)	4.6(4)	0.1(4)
C17	18.6(5)	17.5(5)	19.1(5)	-0.9(4)	6.5(4)	1.4(4)
C18	17.6(5)	17.2(5)	20.6(5)	-1.3(4)	8.9(4)	0.0(4)
C19	17.0(5)	17.9(5)	22.1(5)	-0.5(4)	10.6(4)	-0.7(4)
C20	22.3(5)	22.7(6)	23.5(6)	2.5(5)	12.2(5)	2.5(5)
C21	26.2(6)	21.5(6)	41.1(6)	6.3(5)	15.2(5)	5.0(5)
C22	26.0(6)	18.1(6)	45.8(7)	-2.3(5)	17.0(5)	0.1(5)
C23	22.6(5)	19.7(6)	26.8(6)	-5.0(5)	12.9(5)	-3.1(4)
C24	18.1(5)	18.2(5)	22.3(6)	-1.1(4)	10.2(4)	-1.3(4)
C25	21.9(5)	17.2(5)	21.3(6)	-2.4(4)	7.5(4)	0.5(4)

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TABLE 9

Bond Lengths for 9b.		
Atom	Atom	Length/Å
S1	O1	1.4339(9)
S1	O2	1.4287(9)
S1	N1	1.6664(11)
S1	C1	1.7480(12)
N1	C8	1.4204(15)
N1	C16	1.4354(15)
N2	C24	1.3703(16)
N2	C25	1.3793(16)
C1	C2	1.3885(16)
C1	C6	1.3954(16)
C2	C3	1.3884(17)
C3	C4	1.3947(17)
C4	C5	1.3997(18)
C4	C7	1.5054(17)
C5	C6	1.3842(17)
C8	C9	1.3947(17)
C8	C13	1.4026(17)
C9	C10	1.3935(18)
C10	C11	1.397(2)
C11	C12	1.3863(19)
C12	C13	1.3992(17)
C13	C14	1.4444(16)
C14	C15	1.4969(17)
C14	C16	1.3569(16)
C16	C17	1.4984(16)
C17	C18	1.5096(16)
C18	C19	1.4373(16)
C18	C25	1.3696(17)
C19	C20	1.4009(17)
C19	C24	1.4165(17)
C20	C21	1.3846(18)
C21	C22	1.405(2)
C22	C23	1.3814(19)
C23	C24	1.3954(17)

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TABLE 10

Bond Angles for 9b.							
Atom	Atom	Atom	Angle/°	Atom	Atom	Atom	Angle/°
O1	S1	N1	106.72(5)	C11	C12	C13	118.50(12)
O1	S1	C1	108.34(6)	C8	C13	C14	108.24(10)
O2	S1	O1	119.08(6)	C12	C13	C8	119.84(11)
O2	S1	N1	106.01(6)	C12	C13	C14	131.92(12)
O2	S1	C1	108.97(6)	C13	C14	C15	124.73(11)
N1	S1	C1	107.11(5)	C16	C14	C13	108.06(11)
C8	N1	S1	122.10(8)	C16	C14	C15	127.18(11)
C8	N1	C16	107.59(9)	N1	C16	C17	123.79(10)
C16	N1	S1	126.82(8)	C14	C16	N1	108.94(10)
C24	N2	C25	108.85(11)	C14	C16	C17	127.10(11)
C2	C1	S1	118.95(9)	C16	C17	C18	114.48(10)
C2	C1	C6	121.65(11)	C19	C18	C17	125.42(11)
C6	C1	S1	119.36(9)	C25	C18	C17	128.48(11)
C3	C2	C1	118.64(11)	C25	C18	C19	106.10(10)
C2	C3	C4	121.16(11)	C20	C19	C18	134.16(12)
C3	C4	C5	118.82(11)	C20	C19	C24	118.64(11)
C3	C4	C7	120.56(12)	C24	C19	C18	107.20(10)
C5	C4	C7	120.59(11)	C21	C20	C19	119.16(12)
C6	C5	C4	121.05(11)	C20	C21	C22	120.91(12)
C5	C6	C1	118.66(11)	C23	C22	C21	121.54(12)
C9	C8	N1	130.77(11)	C22	C23	C24	117.20(12)
C9	C8	C13	122.11(11)	N2	C24	C19	107.55(10)
C13	C8	N1	107.11(10)	N2	C24	C23	129.91(12)
C10	C9	C8	116.99(12)	C23	C24	C19	122.53(11)
C9	C10	C11	121.59(12)	C18	C25	N2	110.29(11)
C12	C11	C10	120.97(12)				

TABLE 11

Hydrogen Bonds for 9b.				
D H A	d(D-H)/Å	d(H-A)/Å	d(D-A)/Å	D-H-A/°
N2 H2 O1 <sup>1</sup>	0.877(18)	2.123(19)	2.9766(16)	164.2(16)

<sup>1</sup>1-X, 1-Y, 2-Z

TABLE 12

Torsion Angles for 9b.									
A	B	C	D	Angle/°	A	B	C	D	Angle/°
S1	N1	C8	C9	-18.46(17)	C9	C10	C11	C12	-0.1(2)
S1	N1	C8	C13	162.66(8)	C10	C11	C12	C13	-0.05(19)
S1	N1	C16	C14	-161.64(9)	C11	C12	C13	C8	0.25(18)
S1	N1	C16	C17	22.74(16)	C11	C12	C13	C14	-179.65(12)
S1	C1	C2	C3	178.36(9)	C12	C13	C14	C15	-1.9(2)
S1	C1	C6	C5	-179.06(9)	C12	C13	C14	C16	179.71(12)
O1	S1	N1	C8	171.33(9)	C13	C8	C9	C10	0.21(18)
O1	S1	N1	C16	-32.44(11)	C13	C14	C16	N1	1.73(13)
O1	S1	C1	C2	-145.08(9)	C13	C14	C16	C17	177.17(11)
O1	S1	C1	C6	32.69(11)	C14	C16	C17	C18	-94.30(14)
O2	S1	N1	C8	43.43(10)	C15	C14	C16	N1	-176.62(11)
O2	S1	N1	C16	-160.33(9)	C15	C14	C16	C17	-1.2(2)
O2	S1	C1	C2	-14.13(11)	C16	N1	C8	C9	-178.67(12)
O2	S1	C1	C6	163.64(9)	C16	N1	C8	C13	2.44(12)
N1	S1	C1	C2	100.13(10)	C16	C17	C18	C19	123.67(12)
N1	S1	C1	C6	-82.10(10)	C16	C17	C18	C25	-56.27(17)
N1	C8	C9	C10	-178.53(12)	C17	C18	C19	C20	-0.9(2)
N1	C8	C13	C12	178.66(10)	C17	C18	C19	C24	179.35(11)
N1	C8	C13	C14	-1.42(12)	C17	C18	C25	N2	-179.92(11)
N1	C16	C17	C18	80.51(14)	C18	C19	C20	C21	-178.79(12)
C1	S1	N1	C8	-72.81(10)	C18	C19	C24	N2	1.01(13)
C1	S1	N1	C16	83.42(11)	C18	C19	C24	C23	-179.74(11)
C1	C2	C3	C4	0.32(18)	C19	C18	C25	N2	0.13(14)
C2	C1	C6	C5	-1.35(18)	C19	C20	C21	C22	-1.32(19)
C2	C3	C4	C5	-0.55(18)	C20	C19	C24	N2	-178.77(10)
C2	C3	C4	C7	-178.82(12)	C20	C19	C24	C23	0.49(17)
C3	C4	C5	C6	-0.19(19)	C20	C21	C22	C23	0.3(2)
C4	C5	C6	C1	1.11(18)	C21	C22	C23	C24	1.02(18)
C6	C1	C2	C3	0.64(18)	C22	C23	C24	N2	177.63(12)



TABLE 12-continued

Torsion Angles for 9b.									
A	B	C	D	Angle/°	A	B	C	D	Angle/°
C7	C4	C5	C6	178.08(12)	C22	C23	C24	C19	-1.44(18)
C8	N1	C16	C14	-2.63(13)	C24	N2	C25	C18	0.51(14)
C8	N1	C16	C17	-178.24(10)	C24	C19	C20	C21	0.91(17)
C8	C9	C10	C11	-0.01(19)	C25	N2	C24	C19	-0.94(13)
C8	C13	C14	C15	178.20(11)	C25	N2	C24	C23	179.88(12)
C8	C13	C14	C16	-0.20(13)	C25	C18	C19	C20	179.03(13)
C9	C8	C13	C12	-0.34(18)	C25	C18	C19	C24	-0.69(13)
C9	C8	C13	C14	179.58(11)					

TABLE 13

Hydrogen Atom Coordinates ( $\text{\AA} \times 10^4$ ) and Isotropic Displacement Parameters ( $\text{\AA}^2 \times 10^3$ ) for 9b.				
Atom	x	y	z	U(eq)
H2	5253(14)	6801(16)	10233(14)	30(4)
H2A	5784	772	7130	22
H3	4880	-545	5854	25
H5	2258	1571	5065	25
H6	3134	2876	6357	22
H7A	3389	-1116	4488	45
H7B	2636	-70	3877	45
H7C	2290	-821	4673	45
H9	7364	2376	7633	26
H10	8706	2582	6903	31
H11	8696	4170	5859	32
H12	7347	5606	5504	28
H15A	5893	7281	5990	35
H15B	4647	6986	5727	35
H15C	5269	6543	5004	35
H17A	3657	4835	7065	22
H17B	3701	6007	6455	22
H20	3119	8035	6624	26
H21	2813	9919	7142	30
H22	3442	10432	8834	30
H23	4410	9082	10053	26
H25	5256	5172	9131	24

## (12.2) Structural Report on Compound 13:

## (12.2.1) Data Collection:

A colorless crystal with approximate dimensions  $0.56 \times 0.47 \times 0.44 \text{ mm}^3$  was selected under oil under ambient conditions and attached to the tip of a MiTeGen MicroMount<sup>®</sup>. The crystal was mounted in a stream of cold nitrogen at 100(1) K and centered in the X-ray beam by using a video camera.

The crystal evaluation and data collection were performed on a Bruker SMART APEXII diffractometer with Cu  $K_{\alpha}$  ( $\lambda=1.54178 \text{ \AA}$ ) radiation and the diffractometer to crystal distance of 4.03 cm.

The initial cell constants were obtained from three series of  $\omega$  scans at different starting angles. Each series consisted of 35 frames collected at intervals of  $0.6^\circ$  in a  $25^\circ$  range about  $\omega$  with the exposure time of 2 seconds per frame. The reflections were successfully indexed by an automated indexing routine built in the APEXII program. The final cell constants were calculated from a set of 9384 strong reflections from the actual data collection.

The data were collected by using the full sphere data collection routine to survey the reciprocal space to the extent of a full sphere to a resolution of  $0.82 \text{ \AA}$ . A total of 46397 data were harvested by collecting 22 sets of frames with  $0.7^\circ$  scans in  $\omega$  and  $\varphi$  with an exposure time 5-10 sec per frame. These highly redundant datasets were corrected for Lorentz and polarization effects. The absorption correction was based on fitting a function to the empirical transmission

15 surface as sampled by multiple equivalent measurements. Bruker-AXS. (2007-2014) APEX2 (Ver. 2014.1-1), SADABS (2012-1), and SAINT+ (Ver. 8.32A) Software Reference Manuals. Bruker-AXS, Madison, Wis., USA.

## (12.2.2) Structure Solution and Refinement:

20 The systematic absences in the diffraction data were uniquely consistent for the space group  $P2_1/c$  that yielded chemically reasonable and computationally stable results of refinement. Sheldrick, G. M. (2008) SHELXL. *Acta Cryst. A* 64, 112-122. Dolomanov, O. V.; Bourhis, L. J.; Gildea, R. J.; Howard, J. A. K.; Puschmann, H. "OLEX2: a complete structure solution, refinement and analysis program". *J. Appl. Cryst.* (2009) 42, 339-341. Guzei, I. A. (2013). Internal laboratory computer programs Gn.

A successful solution by the direct methods provided most non-hydrogen atoms from the E-map. The remaining non-hydrogen atoms were located in an alternating series of least-squares cycles and difference Fourier maps. All non-hydrogen atoms were refined with anisotropic displacement coefficients. All hydrogen atoms except H1(N1) and H2(N2) were included in the structure factor calculation at idealized positions and were allowed to ride on the neighboring atoms with relative isotropic displacement coefficients. Atoms H1 and H2 were located in the difference Fourier map and refined independently

40 The final least-squares refinement of 333 parameters against 4996 data resulted in residuals R (based on  $F^2$  for  $I \geq 2\sigma$ ) and  $wR$  (based on  $F^2$  for all data) of 0.0348 and 0.0893, respectively. The final difference Fourier map was featureless.

## (12.2.3) Summary:

45 Crystal Data for  $C_{31}H_{26}N_2O_2S$  ( $M=490.60$ ): monoclinic, space group  $P2_1/c$  (no. 14),  $a=14.1262(11) \text{ \AA}$ ,  $b=9.3818(5) \text{ \AA}$ ,  $c=20.2526(8) \text{ \AA}$ ,  $\beta=108.247(5)^\circ$ ,  $V=2549.1(3) \text{ \AA}^3$ ,  $Z=4$ ,  $T=99.98 \text{ K}$ ,  $\mu(\text{CuK}\alpha)=1.370 \text{ mm}^{-1}$ ,  $D_{\text{calc}}=1.278 \text{ g/mm}^3$ , 46397 reflections measured ( $6.588 \leq 2\theta \leq 145.99$ ), 4996 unique ( $R_{\text{int}}=0.0173$ ,  $R_{\text{sigma}}=0.0083$ ) which were used in all calculations. The final  $R_1$  was 0.0348 ( $I > 2\sigma(I)$ ) and  $wR_2$  was 0.0893 (all data).

TABLE 14

Crystal data and structure refinement for 13.	
Identification code	13
Empirical formula	$C_{31}H_{26}N_2O_2S$
Formula weight	490.60
Temperature/K	99.98
Crystal system	monoclinic
Space group	$P2_1/c$
$a/\text{\AA}$	14.1262(11)
$b/\text{\AA}$	9.3818(5)
$c/\text{\AA}$	20.2526(8)
$\alpha/^\circ$	90
$\beta/^\circ$	108.247(5)

TABLE 14-continued

Crystal data and structure refinement for 13.	
$\gamma/^\circ$	90
Volume/ $\text{\AA}^3$	2549.1(3)
Z	4
$\rho_{\text{calc}}/\text{mg}/\text{mm}^3$	1.278
$m/\text{mm}^{-1}$	1.370
F(000)	1032.0
Crystal size/ $\text{mm}^3$	$0.56 \times 0.47 \times 0.44$
Radiation	$\text{CuK}\alpha$ ( $\lambda = 1.54178$ )
$2\theta$ range for data collection	$6.588$ to $145.99^\circ$
Index ranges	$-17 \leq h \leq 16$ , $-11 \leq k \leq 11$ , $-25 \leq l \leq 25$
Reflections collected	46397
Independent reflections	4996 [ $R_{\text{int}} = 0.0173$ , $R_{\text{sigma}} = 0.0083$ ]
Data/restraints/parameters	4996/0/333
Goodness-of-fit on $F^2$	1.055
Final R indexes [ $I \geq 2\sigma(I)$ ]	$R_1 = 0.0348$ , $wR_2 = 0.0892$
Final R indexes [all data]	$R_1 = 0.0349$ , $wR_2 = 0.0893$
Largest diff. peak/hole/ $e \text{\AA}^{-3}$	0.32/-0.49

TABLE 15

Fractional Atomic Coordinates ( $\times 10^4$ ) and Equivalent Isotropic Displacement Parameters ( $\text{\AA}^2 \times 10^3$ ) for 13. $U_{\text{eq}}$ is defined as $1/3$ of the trace of the orthogonalised $U_{ij}$ tensor.				
Atom	x	y	z	$U(\text{eq})$
S1	7366.3(2)	5399.3(3)	6318.8(2)	15.13(9)
O1	8059.2(7)	5873.2(10)	6961.2(5)	23.2(2)
O2	6353.3(6)	5887.7(9)	6118.7(5)	19.66(19)
N1	7256.0(8)	3670.0(11)	6335.8(5)	16.1(2)
N2	5753.8(8)	3114.4(12)	4033.4(6)	21.1(2)
C1	7877.8(9)	5798.4(13)	5654.3(6)	17.4(2)

TABLE 15-continued

Fractional Atomic Coordinates ( $\times 10^4$ ) and Equivalent Isotropic Displacement Parameters ( $\text{\AA}^2 \times 10^3$ ) for 13. $U_{\text{eq}}$ is defined as $1/3$ of the trace of the orthogonalised $U_{ij}$ tensor.				
Atom	x	y	z	$U(\text{eq})$
C2	7258.7(10)	5775.3(13)	4967.3(7)	20.7(3)
C3	7660.2(11)	6070.6(14)	4442.0(7)	25.6(3)
C4	8668.6(12)	6382.9(17)	4590.4(8)	31.5(3)
C5	9271.7(11)	6388.6(19)	5279.9(9)	34.9(4)
C6	8884.6(10)	6106.6(16)	5817.5(7)	26.4(3)
C7	9097.1(14)	6719(2)	4013.2(10)	50.8(5)
C8	8022.9(9)	2633.1(13)	6456.8(6)	16.4(2)
C9	8976.6(9)	2941.7(15)	6897.2(6)	21.8(3)
C10	9717(1)	1908.2(17)	7044.8(7)	27.1(3)
C11	9501.1(11)	563.0(17)	6760.4(7)	29.5(3)
C12	8550.8(11)	252.4(15)	6324.1(7)	25.6(3)
C13	7794.3(9)	1274.7(14)	6152.0(6)	18.1(3)
C14	6755.2(9)	930.3(13)	5636.0(6)	17.6(2)
C15	5990.4(9)	1242.1(13)	5976.5(6)	18.5(3)
C16	5396.4(9)	1571.5(13)	6262.7(6)	18.8(3)
C17	4721.5(9)	1972.1(13)	6634.6(6)	17.4(2)
C18	4892.6(10)	3213.0(14)	7038.8(7)	20.9(3)
C19	4268(1)	3557.7(14)	7424.1(7)	23.5(3)
C20	3473.1(10)	2679.0(15)	7413.3(7)	23.4(3)
C21	3297(1)	1447.5(15)	7012.1(7)	23.4(3)
C22	3913(1)	1094.2(14)	6622.3(7)	20.5(3)
C23	6645.8(11)	-658.8(14)	5420.5(8)	25.6(3)
C24	6556.5(9)	1821.6(12)	4976.2(6)	16.0(2)
C25	7166.8(9)	1884.9(13)	4524.8(6)	17.7(2)
C26	8093.4(10)	1300.1(15)	4544.5(7)	24.8(3)
C27	8440.3(12)	1529.9(18)	3986.6(8)	32.8(3)
C28	7897.5(12)	2345.5(18)	3411.2(8)	33.5(3)
C29	6991.2(11)	2937.3(15)	3378.2(7)	27.1(3)
C30	6632.9(10)	2692.8(13)	3936.8(6)	19.9(3)
C31	5710.5(9)	2575.0(13)	4654.1(6)	18.7(2)

TABLE 16

Anisotropic Displacement Parameters ( $\text{\AA}^2 \times 10^3$ ) for 13. The Anisotropic displacement factor exponent takes the form:  
 $-2\pi^2[h^2a^{*2}U_{11} + 2hka^{*}b^{*}U_{12} + \dots]$ .

Atom	$U_{11}$	$U_{22}$	$U_{33}$	$U_{23}$	$U_{13}$	$U_{12}$
S1	13.59(16)	15.99(15)	16.54(15)	-4.14(10)	5.76(12)	-1.95(10)
O1	19.1(5)	30.0(5)	21.0(5)	-10.2(4)	6.8(4)	-5.5(4)
O2	17.1(4)	18.1(4)	25.0(4)	-3.0(3)	8.2(4)	0.8(3)
N1	11.1(5)	16.9(5)	18.9(5)	0.0(4)	2.5(4)	-1.3(4)
N2	19.6(6)	20.3(5)	19.2(5)	3.0(4)	0.1(4)	0.6(4)
C1	19.3(6)	14.0(5)	21.5(6)	-1.3(5)	9.8(5)	-0.8(4)
C2	23.8(7)	16.5(6)	22.5(6)	-1.1(5)	8.1(5)	-3.1(5)
C3	34.7(8)	21.4(6)	22.1(6)	2.6(5)	11.1(6)	1.5(5)
C4	35.4(8)	33.2(8)	33.1(8)	10.3(6)	21.2(7)	6.7(6)
C5	22.3(7)	47.2(9)	39.5(8)	9.4(7)	15.9(6)	-0.6(6)
C6	20.4(7)	32.9(7)	26.9(7)	1.6(6)	9.1(5)	-1.8(5)
C7	45.7(10)	74.7(13)	43.1(10)	23.9(9)	30.2(9)	12.8(9)
C8	14.3(6)	22.4(6)	13.4(5)	4.9(5)	5.3(4)	3.3(5)
C9	16.8(6)	33.3(7)	14.9(6)	2.9(5)	4.3(5)	0.9(5)
C10	15.8(6)	48.4(9)	15.9(6)	8.9(6)	3.4(5)	7.5(6)
C11	24.0(7)	43.5(9)	21.9(7)	12.9(6)	8.4(6)	19.7(6)
C12	30.0(7)	26.1(7)	22.4(6)	6.9(5)	10.7(6)	12.4(6)
C13	18.7(6)	21.4(6)	15.7(6)	5.6(5)	7.6(5)	4.4(5)
C14	19.3(6)	12.8(6)	20.7(6)	1.4(5)	6.4(5)	1.2(4)
C15	18.7(6)	14.3(5)	21.4(6)	3.0(5)	4.9(5)	-2.7(5)
C16	18.5(6)	16.0(6)	20.4(6)	3.6(5)	3.8(5)	-2.9(5)
C17	18.0(6)	17.7(6)	15.4(5)	4.1(4)	3.7(5)	-0.1(5)
C18	19.5(6)	19.1(6)	21.3(6)	1.4(5)	2.4(5)	-3.9(5)
C19	29.3(7)	20.4(6)	18.4(6)	-1.7(5)	3.9(5)	0.2(5)
C20	27.5(7)	26.6(7)	18.5(6)	4.5(5)	10.8(5)	3.7(5)
C21	23.4(7)	23.8(7)	25.0(6)	4.5(5)	10.3(5)	-4.2(5)
C22	22.9(6)	18.0(6)	20.4(6)	0.1(5)	6.5(5)	-3.7(5)
C23	32.3(8)	13.7(6)	31.7(7)	0.8(5)	11.3(6)	-0.2(5)
C24	15.6(6)	13.7(5)	17.1(6)	-2.4(4)	3.1(5)	-3.0(4)
C25	20.1(6)	15.6(6)	16.4(6)	-4.5(4)	4.2(5)	-3.8(5)
C26	22.8(7)	29.1(7)	22.6(6)	-3.2(5)	7.2(5)	2.1(5)

TABLE 16-continued

Anisotropic Displacement Parameters ( $\text{\AA}^2 \times 10^3$ ) for 13. The Anisotropic displacement factor exponent takes the form:  
 $-2\pi^2[h^2a^*U_{11} + 2hka^*b^*U_{12} + \dots]$ .

Atom	$U_{11}$	$U_{22}$	$U_{33}$	$U_{23}$	$U_{13}$	$U_{12}$
C27	28.8(8)	43.6(9)	30.4(7)	-7.8(6)	15.4(6)	0.9(6)
C28	41.3(9)	41.7(9)	23.0(7)	-6.4(6)	17.7(6)	-8.1(7)
C29	36.7(8)	26.7(7)	17.2(6)	-1.9(5)	7.4(6)	-6.4(6)
C30	22.7(6)	16.7(6)	17.7(6)	-4.1(5)	2.7(5)	-5.3(5)
C31	17.4(6)	16.7(6)	21.0(6)	0.5(5)	4.7(5)	-2.1(5)

TABLE 17

Bond Lengths for 13.

Atom	Atom	Length/ $\text{\AA}$
S1	O1	1.4321(9)
S1	O2	1.4347(9)
S1	N1	1.6313(11)
S1	C1	1.7557(12)
N1	C8	1.4191(15)
N2	C30	1.3743(18)
N2	C31	1.3743(17)
C1	C2	1.3927(18)
C1	C6	1.3861(18)
C2	C3	1.3813(19)
C3	C4	1.392(2)
C4	C5	1.390(2)
C4	C7	1.509(2)
C5	C6	1.388(2)
C8	C9	1.3935(18)
C8	C13	1.4088(18)
C9	C10	1.3884(19)
C10	C11	1.381(2)
C11	C12	1.388(2)
C12	C13	1.3965(18)
C13	C14	1.5461(17)
C14	C15	1.4815(17)
C14	C23	1.5475(17)
C14	C24	1.5260(17)
C15	C16	1.2000(19)
C16	C17	1.4377(17)
C17	C18	1.4000(18)
C17	C22	1.4021(17)
C18	C19	1.3867(19)
C19	C20	1.3876(19)
C20	C21	1.389(2)
C21	C22	1.3858(19)
C24	C25	1.4409(17)
C24	C31	1.3656(17)
C25	C26	1.4082(18)
C25	C30	1.4140(18)
C26	C27	1.382(2)
C27	C28	1.404(2)
C28	C29	1.378(2)
C29	C30	1.3953(19)

TABLE 18

Bond Angles for 13.

Atom	Atom	Atom	Angle/ $^\circ$	Atom	Atom	Atom	Angle/ $^\circ$
O1	S1	O2	119.67(5)	C15	C14	C13	108.69(10)
O1	S1	N1	109.40(6)	C15	C14	C23	107.37(10)
O1	S1	C1	107.57(6)	C15	C14	C24	109.78(10)
O2	S1	N1	103.31(5)	C24	C14	C13	110.65(10)
O2	S1	C1	109.20(6)	C24	C14	C23	107.83(10)
N1	S1	C1	107.05(6)	C16	C15	C14	176.17(13)
C8	N1	S1	127.78(9)	C15	C16	C17	177.40(13)
C31	N2	C30	108.98(11)	C18	C17	C16	120.16(11)
C2	C1	S1	118.82(10)	C18	C17	C22	119.30(12)
C6	C1	S1	119.97(10)	C22	C17	C16	120.48(11)
C6	C1	C2	121.19(12)	C19	C18	C17	119.95(12)
C3	C2	C1	119.05(12)	C18	C19	C20	120.46(12)
C2	C3	C4	121.01(13)	C19	C20	C21	119.94(12)
C3	C4	C7	120.57(15)	C22	C21	C20	120.18(12)
C5	C4	C3	118.80(13)	C21	C22	C17	120.17(12)
C5	C4	C7	120.62(15)	C25	C24	C14	126.55(11)
C6	C5	C4	121.29(14)	C31	C24	C14	126.54(11)
C1	C6	C5	118.65(13)	C31	C24	C25	106.47(11)
C9	C8	N1	120.06(12)	C26	C25	C24	134.55(12)
C9	C8	C13	120.76(12)	C26	C25	C30	118.59(12)
C13	C8	N1	119.12(11)	C30	C25	C24	106.81(11)
C10	C9	C8	120.32(13)	C27	C26	C25	118.71(13)
C11	C10	C9	119.69(13)	C26	C27	C28	121.49(14)
C10	C11	C12	120.05(13)	C29	C28	C27	121.15(13)
C11	C12	C13	121.80(14)	C28	C29	C30	117.51(13)
C8	C13	C14	121.61(11)	N2	C30	C25	107.56(11)
C12	C13	C8	117.35(12)	N2	C30	C29	129.89(13)
C12	C13	C14	121.03(12)	C29	C30	C25	122.53(13)
C13	C14	C23	112.45(10)	C24	C31	N2	110.16(11)

TABLE 19

Hydrogen Bonds for 13.

D H A	d(D-H)/ $\text{\AA}$	d(H-A)/ $\text{\AA}$	d(D-A)/ $\text{\AA}$	D-H-A/ $^\circ$
N2 H2 O2 <sup>1</sup>	0.859(18)	2.453(17)	3.0426(15)	126.4(14)

<sup>1</sup>I-X, I-Y, I-Z

TABLE 20

Torsion Angles for 13.

A	B	C	D	Angle/ $^\circ$	A	B	C	D	Angle/ $^\circ$
S1	N1	C8	C9	32.08(16)	C12	C13	C14	C24	-114.28(13)
S1	N1	C8	C13	-150.78(10)	C13	C8	C9	C10	-0.28(18)
S1	C1	C2	C3	-179.18(10)	C13	C14	C24	C25	56.04(15)
S1	C1	C6	C5	178.66(12)	C13	C14	C24	C31	-132.53(13)
O1	S1	N1	C8	-56.14(11)	C14	C24	C25	C26	-4.7(2)
O1	S1	C1	C2	-164.22(10)	C14	C24	C25	C30	172.53(11)
O1	S1	C1	C6	16.80(13)	C14	C24	C31	N2	-173.26(11)
O2	S1	N1	C8	175.35(10)	C15	C14	C24	C25	176.00(11)
O2	S1	C1	C2	-32.91(12)	C15	C14	C24	C31	-12.57(17)
O2	S1	C1	C6	148.10(11)	C16	C17	C18	C19	-176.78(12)

TABLE 20-continued

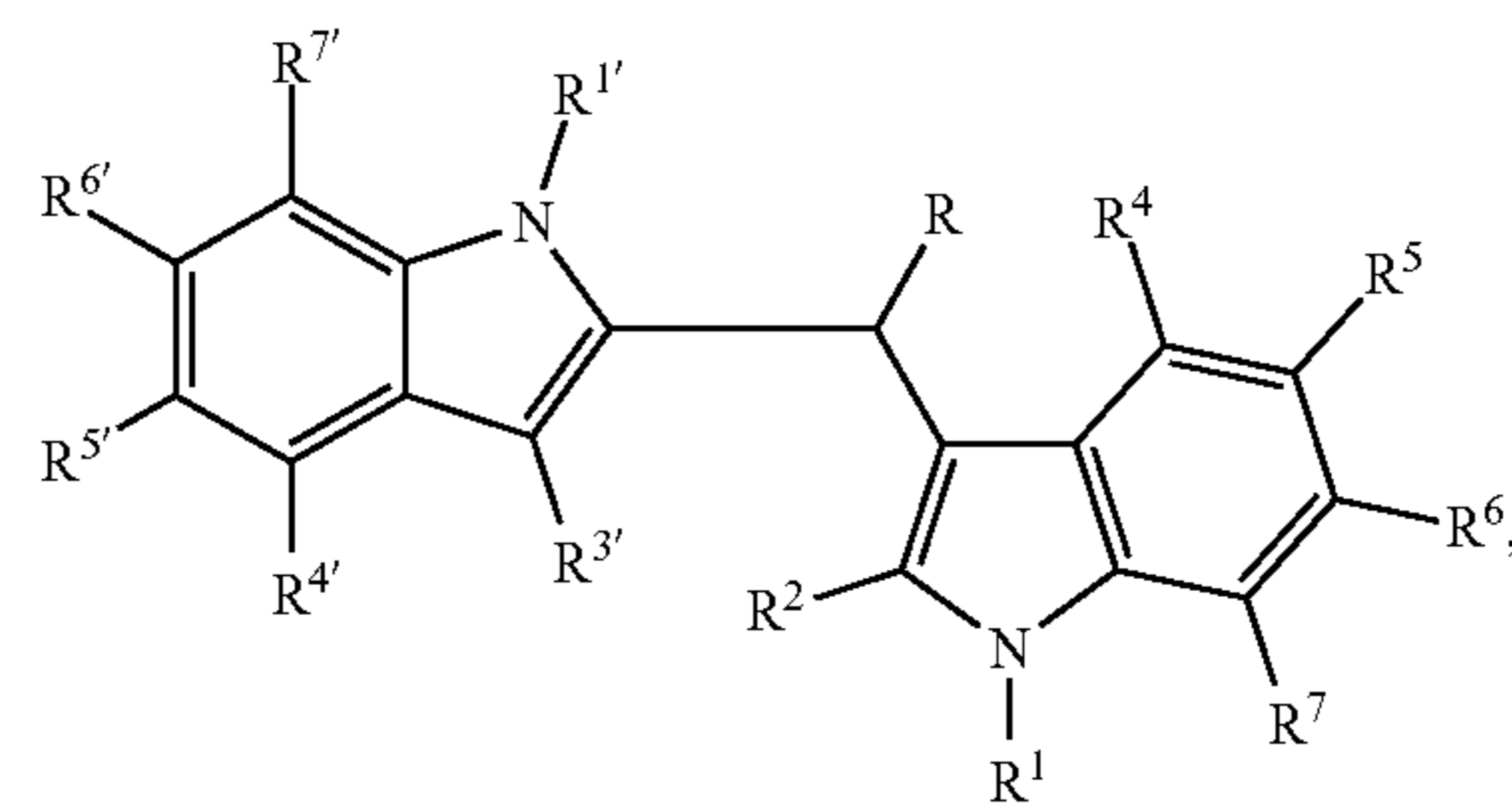
Torsion Angles for 13.									
A	B	C	D	Angle/°	A	B	C	D	Angle/°
N1	S1	C1	C2	78.29(11)	C16	C17	C22	C21	176.49(12)
N1	S1	C1	C6	-100.69(11)	C17	C18	C19	C20	0.1(2)
N1	C8	C9	C10	176.81(11)	C18	C17	C22	C21	-0.61(19)
N1	C8	C13	C12	-175.46(11)	C18	C19	C20	C21	-0.3(2)
N1	C8	C13	C14	5.70(17)	C19	C20	C21	C22	0.0(2)
C1	S1	N1	C8	60.14(11)	C20	C21	C22	C17	0.5(2)
C1	C2	C3	C4	0.2(2)	C22	C17	C18	C19	0.32(19)
C2	C1	C6	C5	-0.3(2)	C23	C14	C24	C25	-67.32(15)
C2	C3	C4	C5	0.2(2)	C23	C14	C24	C31	104.11(14)
C2	C3	C4	C7	-179.34(15)	C24	C25	C26	C27	176.52(14)
C3	C4	C5	C6	-0.8(2)	C24	C25	C30	N2	0.91(13)
C4	C5	C6	C1	0.8(2)	C24	C25	C30	C29	-178.07(12)
C6	C1	C2	C3	-0.21(19)	C25	C24	C31	N2	-0.43(14)
C7	C4	C5	C6	178.82(16)	C25	C26	C27	C28	0.9(2)
C8	C9	C10	C11	-0.89(19)	C26	C25	C30	N2	178.67(11)
C8	C13	C14	C15	-56.09(14)	C26	C25	C30	C29	-0.31(19)
C8	C13	C14	C23	-174.83(11)	C26	C27	C28	C29	-0.6(2)
C8	C13	C14	C24	64.52(14)	C27	C28	C29	C30	-0.2(2)
C9	C8	C13	C12	1.65(17)	C28	C29	C30	N2	-178.11(13)
C9	C8	C13	C14	-177.19(11)	C28	C29	C30	C25	0.6(2)
C9	C10	C11	C12	0.6(2)	C30	N2	C31	C24	1.03(14)
C10	C11	C12	C13	0.8(2)	C30	C25	C26	C27	-0.47(19)
C11	C12	C13	C8	-1.95(19)	C31	N2	C30	C25	-1.19(14)
C11	C12	C13	C14	176.91(12)	C31	N2	C30	C29	177.69(13)
C12	C13	C14	C15	125.11(12)	C31	C24	C25	C26	-177.54(14)
C12	C13	C14	C23	6.37(16)	C31	C24	C25	C30	-0.30(13)

TABLE 21

Hydrogen Atom Coordinates ( $\text{\AA} \times 10^4$ ) and Isotropic Displacement Parameters ( $\text{\AA}^2 \times 10^3$ ) for 13.				
Atom	x	y	z	U(eq)
H1	6676(12)	3411(17)	6097(8)	19
H2	5264(13)	3537(18)	3736(9)	25
H2A	6570	5560	4861	25
H3	7242	6060	3972	31
H5	9962	6589	5385	42
H6	9301	6124	6288	32
H7A	8901	5976	3656	76
H7B	9826	6757	4202	76
H7C	8843	7643	3807	76
H9	9121	3864	7098	26
H10	10369	2125	7340	33
H11	10004	-150	6864	35
H12	8411	-681	6137	31
H18	5436	3818	7049	25
H19	4385	4401	7697	28
H20	3050	2919	7680	28
H21	2753	846	7005	28
H22	3787	255	6346	25
H23A	6746	-1255	5834	38
H23B	7145	-902	5195	38
H23C	5977	-826	5096	38
H26	8473	758	4934	30
H27	9060	1127	3993	39
H28	8160	2492	3038	40
H29	6624	3491	2990	33
H31	5170	2707	4833	22

What is claimed is:

1. A pharmaceutical composition comprising an amount of a compound selected from the group consisting of:



wherein  $R^1$  and  $R^{1'}$  are alkyl; and

each  $R$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^{3'}$ ,  $R^{4'}$ ,  $R^{5'}$ ,  $R^{6'}$ , and  $R^{7'}$  is independently selected from hydrogen, halogen, hydroxyl, substituted or unsubstituted alkyl, substituted or unsubstituted alkoxy, substituted or unsubstituted cycloalkyl, substituted or unsubstituted aryl, substituted or unsubstituted arylalkyl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heteroarylalkyl, substituted or unsubstituted heterocyclyl, or substituted or unsubstituted heterocyclylalkyl;

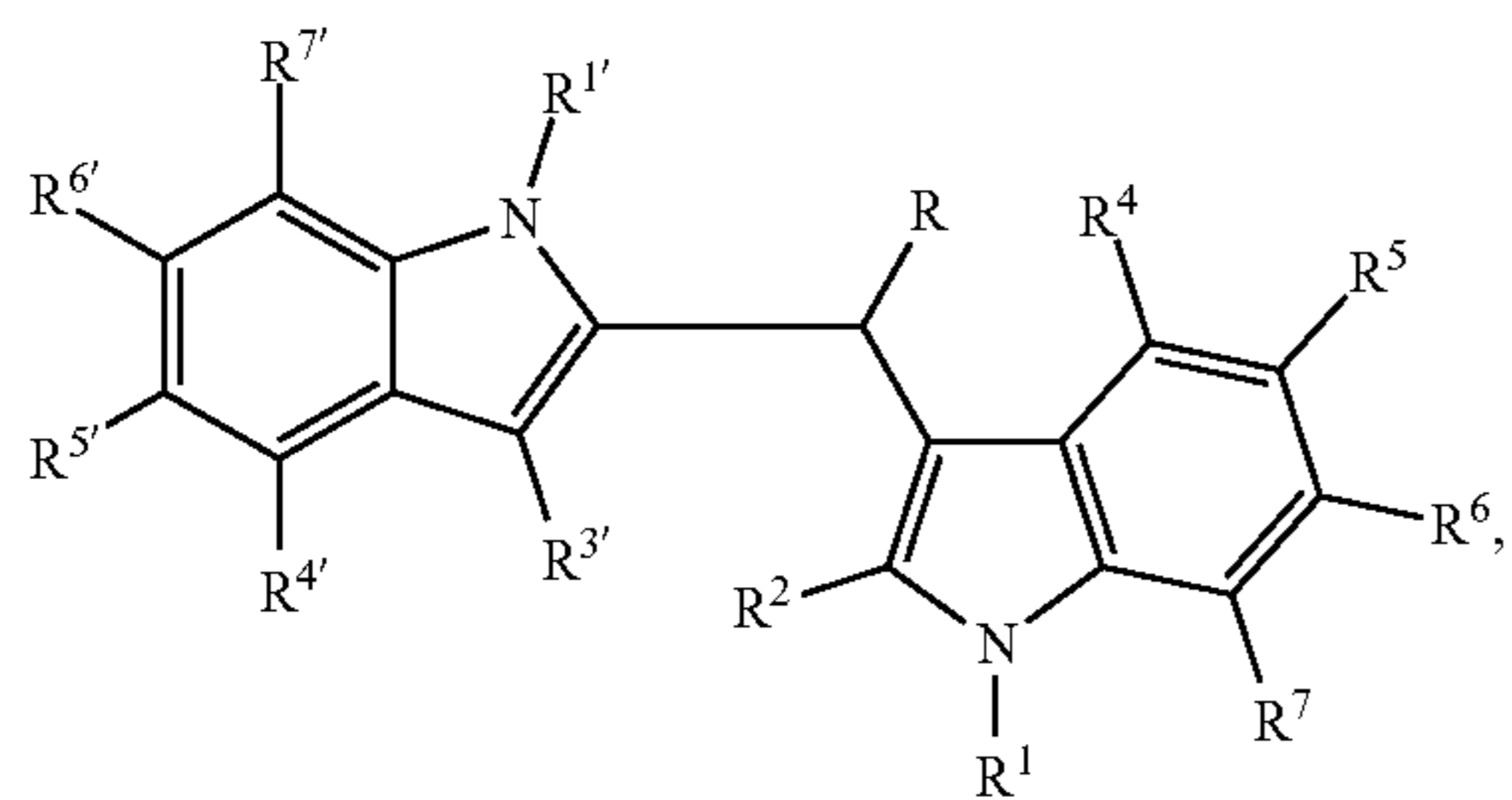
$R^{3'}$  may additionally be selected from acyl ( $-\text{C}(=\text{O})\text{H}$ ); or a pharmaceutically suitable salt thereof;

in combination with a pharmaceutically suitable carrier;

wherein the amount is effective to modulate activity of arylhydrocarbon receptors in mammals, or the amount is effective to inhibit activity of PCSK9 in mammals, or the amount is effective to stimulate secretion of glucagon-like peptide 1 in mammals.

2. A pharmaceutical composition comprising an amount of a compound selected from the group consisting of:

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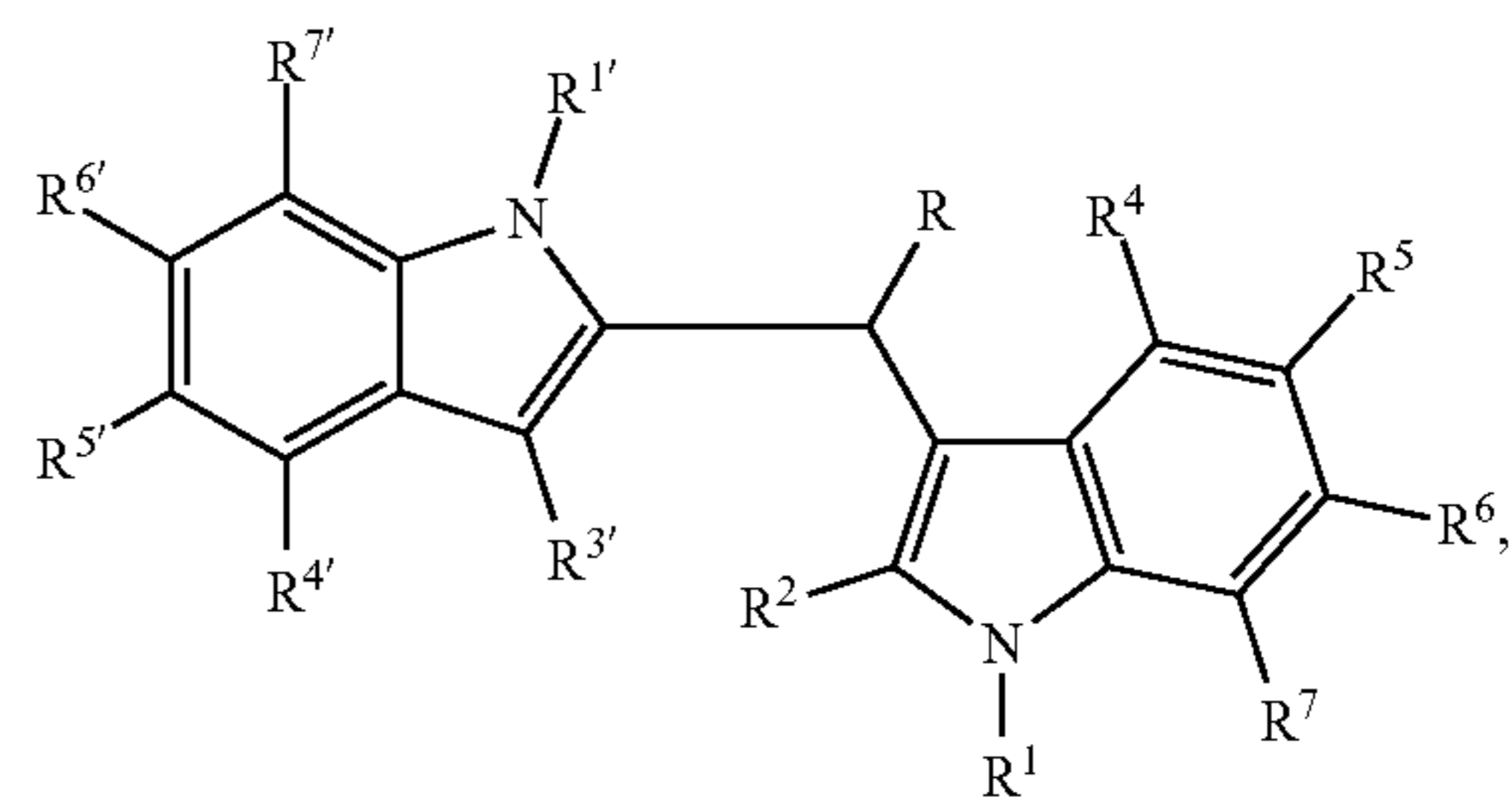
5

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wherein each  $R^1$  and  $R^{1'}$  is independently hydrogen or alkyl; and  
 each  $R$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^{3'}$ ,  $R^{4'}$ ,  $R^{5'}$ ,  $R^{6'}$ , and  $R^{7'}$  is independently selected from hydrogen, halogen, hydroxyl, substituted or unsubstituted alkyl, substituted or unsubstituted alkoxy, substituted or unsubstituted cycloalkyl, substituted or unsubstituted aryl, substituted or unsubstituted arylalkyl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heteroarylalkyl, substituted or unsubstituted heterocyclyl, or substituted or unsubstituted heterocyclylalkyl, and wherein at least one of  $R$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^{3'}$ ,  $R^{4'}$ ,  $R^{5'}$ ,  $R^{6'}$ , and  $R^{7'}$  is halogens  
 $R^{3'}$  may additionally be selected from acyl ( $-\text{C}(=\text{O})\text{H}$ ); or a pharmaceutically suitable salt thereof;  
 in combination with a pharmaceutically suitable carrier; wherein the amount is effective to modulate activity of arylhydrocarbon receptors in mammals, or the amount is effective to inhibit activity of PCSK9 in mammals, or the amount is effective to stimulate secretion of glucagon-like peptide 1 in mammals.

3. A pharmaceutical composition comprising an amount of a compound selected from the group consisting of:

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wherein each  $R^1$  and  $R^{1'}$  is independently hydrogen or alkyl; and

each  $R$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^{3'}$ ,  $R^{4'}$ ,  $R^{5'}$ ,  $R^{6'}$ , and  $R^{7'}$  is independently selected from hydrogen, halogen, hydroxyl, substituted or unsubstituted alkyl, substituted or unsubstituted alkoxy, substituted or unsubstituted cycloalkyl, substituted or unsubstituted aryl, substituted or unsubstituted arylalkyl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heteroarylalkyl, substituted or unsubstituted heterocyclyl, or substituted or unsubstituted heterocyclylalkyl; and

wherein  $R^{3'}$  is acyl;

or a pharmaceutically suitable salt thereof;

in combination with a pharmaceutically suitable carrier;

wherein the amount is effective to modulate activity of arylhydrocarbon receptors in mammals, or the amount is effective to inhibit activity of PCSK9 in mammals, or the amount is effective to stimulate secretion of glucagon-like peptide 1 in mammals.

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